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APOLLO LOGISTICS SUPPORT SYSTEMS MOLAB STUDIES

TELEMETRY SYSTEMS STUDIES FOR A LUNAR MOBILE LABORATORY

Prepared under Contract No. NAS8-5307 by

J. M. Patten

HAYES INTERNATIONAL CORPORATION
Missile and Space Support Division
Apollo Logistics Support Group

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For

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

October 1964

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FOR A

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by

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For

Advanced Studies Office
Astrionics Laboratory

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

ABSTRACT

33867

This report is intended to survey the telemetry field with emphasis on equipment and techniques applicable to the MOLAB mission. The physical properties of size, weight, and power have been stressed and, where feasible, have been related to an individual data channel.

The sections of this report are as follows:

a) The Measurement List. This is a compilation of estimated measurements for the MOLAB mission. This list is detailed in total measurements and in measurements per mode. The scientific instrumentation is given in the form of sketches and discriptions pertinent to each experiment.

b) Transducers. This section describes the operation and function of the conventional sensors with illustrative sketches for operation. A current state-of-the-art list is furnished, describing the salient features.

c) Signal Conditioners. This section deals with the properties of signal conditioners. Various configurations and the advantages of each method are discussed. Physical features are listed in table form to assist in comparative analysis.

d) Data Compression Tape Recorders. A study is given for analog and digital type tape recorders with numerous charts, tables, and nomographs to assist in the evaluation of data compression techniques. Examples are cited in both methods with full descriptions of their characteristics.

e) Telemetry Systems. This section performs an analysis on six major telemetry systems that may contribute to the MOLAB mission. FM/FM, SSFM/FM, PAM/FM, PCM/FM, PACM/FM and PAM/FM/FM are the subjects under discussion. The operating characteristics, system comparison, physical qualities, and channel capacities are given for each system and charts, graphs, and tables in the explanation.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

(Continued)

1.0 MEASUREMENTS LIST

1.1 COMMAND AND CHECKOUT MEASUREMENTS

A measurement list forms the basis for any telemetry system. It contains all the characteristics of the measurand so that a logical telemetry system can be designed for economical transmission.

The characteristics of frequency, accuracy, and the number of measurements are the most important factors in determining the size and type of the system needed. Other characteristics such as wave form, duty cycle, etc., also are used for detailed analysis when a system is being designed.

For this purpose, a "Total Measurement List" (list number one) was generated that includes all modes of operation and consists of the probable measurements that will be taken during the MOLAB mission. The author is aware that omissions and unneeded measurements may appear in this list; however, as an initial working paper, it provides the necessary frame of reference.

The measurement list is sectionalized according to a system or a prime source of power within the MOLAB. Sub-sections are devoted to a breakdown of the measurements with their associated characteristics. Only the major characteristics are entered in this list because at this time only guesswork could provide the minor characteristics. The basis for the number, accuracy, and frequency factors stems from personal contact with cognizant engineers on the MOLAB project and a literature search of existing systems.

Estimating the required frequency response for RPM and frequency measurands is difficult as this is dictated to a large degree by the type of transducer used for the measurement. For many measurements that will assume a quasi DC level, a maximum of 2 cycles per second was allowed with reservation for eventual reduction if the operational system required this bandwidth.

In addition to the "Total Measurement List", a summary data sheet acts as an extract, giving for the measurements the total number plus the maximum frequency and accuracy encountered for any one type.

As currently conceived, the MOLAB will operate under three distinct modes: 1) the dormant, at which time only the periodic checkout and control aspects and some scientific experimentation will be conducted; 2) the unmanned roving mode, when remote guidance via television and instrumentation will predominate and; 3) the manned mode, where the astronaut assumes primary control of the vehicle. Each of these modes requires some variation in the telemetry system for optimum performance. By projecting these variations into three separate lists corresponding to the modes, a diagnostic working paper can be formulated. (See lists Two, Three, and Four.) Each of these lists includes a summary sheet, giving salient points on the measurements for ease of comparison.

During the dormant mode, a requirement for emergency transmission with reduced power and bandwidth may be needed. For this reason a selected group of measurements was designated as "vital" on this list.

No attempt has been made to include in the formal measurement lists any scientific instrumentation as the properties and requirements of this group are more easily detailed in a subsequent section of this report.

SUMMARY SHEET FOR THE TOTAL MEASUREMENT LIST

Total Analog Measurements	=	417
Total Bi-Level Measurements	=	57
Total		476

BREAKDOWN OF ANALOG MEASUREMENTS

MEASUREMENT	NUMBER	MAX. FREQ	MAX. ACCURACY	REMARKS
1. Temperature	150	2	2	
2. Voltage	70	2	2	
3. Current	55	2	2	
4. Pressure	30	10	2	
5. Bio Medical	25	30	2	Assume discriminator with FM/FM
6. Navigation	22	Unknown	.5	
7. Nuclear Count	10	10	5	
8. R.P.M	8	*	2	See below (*)
9. Position	7	10	2	
10. Volt/Second	6	2	2	
11. Flow	6	20	2	Freq. function of end instrument
12. Level	6	2	5	
13. Frequency	5	*	2	See below (*)
14. Purity	3	2	2	
15. Quantity	3	2	5	
16. Wattage	4	2	5	
17. Gas Analysis	4	2	2	
18. Heading	2	2	2	
19. Acceleration	1	20	2	Freq. function of end instrument/ signal-conditioning
20. Bi-Level	59	N.A.	N.A.	

* The frequency response is a direct function of signal conditioning and although the R.P.M.(speed of drive motor) is approx 3600, it is misleading to give this figure.

1.2 MEASUREMENT LISTS

1.2.1 TOTAL MEASUREMENT LISTS

(1) System Function	(2) Tenative Measurements	(3) Number Tent.	Corr.	(4) Percent Accuracy	(5) Max Freq	(6) Duty Cycle	(7) Wave Form	(8) Time V.S. Level Change	(9) Bi-Level	(10) Remarks	(11) Ref. No.
External Environment	Temperature	20		2	2						
	Pressure	2		2	2						
	Position of MOLAB	3		2	10						
Nuclear Elec Energy	Voltage Out	2		5	2						
	Current Out	2		2	2						
	Disintergration	10		5	10						
	Temperature	30		2	2						
Battery	V.S. into Battery	3		2	2						
	V.S. from Battery	3		2	2						
	Temperature	9		2	2						
	Voltage to Charger	3		5	2						
	Current to Charger	3		5	2						
	Voltage from Charger	3		5	2						
	Current from Charger	3		5	2						
Fuel Cells	Output Voltage	3		5	2						
	Output Current	3		2	2						
	$H_2 + O_2$ Level (Cryo)	6		5	2						
	$H_2 + O_2$ Press (Cryo)	6		5	2						
	$H_2 + O_2$ Flow (Cryo)	6		5	2						
	$H_2 + O_2$ Press (Gas)	6		5	2						
	$H_2 + O_2$ Temp (Gas)	6		5	2						
	Cell Temp	3		2	2						
	H_2 Coolent Temp	3		5	2						
	$H_2 + O_2$ Value Closure	6		-	-						

(1) System Function	(2) Tenative Measurements	(3) Number Tent	Corr.	(4) Percent Accuracy	(5) Max Freq	(6) Duty Cycle	(7) Wave Form	(8) Time V.S. Level Change	(9) Bi-Level	(10) Remarks	(11) Ref. No.
Radiator	Inlet Temperature	6		5	2						
	Outlet Temperature	6		5	2						
	Δ Pressure	6		5	10						
Potable H_2O	Temperature	3		5	2						
	Pressure	3		5	2						
	Purity	3		2	2						
	Quanity	3		5	2						
Inverters	Voltage In	5		5	- see remarks						
	Current In	5		2	-						
	Voltage Out	15		5	-						
	Current Out	15		2	-						
	Frequency Out	5		2	-						
	Temperature	10		5	2						
Converters	Voltage In	10		5	2						
	Current In	10		2	2						
	Voltage Out	10		5	2						
	Current Out	10		2	2						
	Temperature	20		5	2						

(1) System Function	(2) Tenative Measurements	(3) Number Tent	Corr	(4) Percent Accuracy	(5) Max Freq	(6) Duty Cycle	(7) Wave Form	(8) Time V.S. Level Change	(9) Bi-Level	(10) Remarks	(11) Ref. No.
Communications											
1. Signal Condit.	Voltage In	5		5	2						
2. Encoder	Voltage In	2		5	2						
3. T/M Xmitter	Voltage In	2		5	2						
	Wattage Out	2		5	2						
4. Television	Position	1		2	5						
a) Vidicon	Target Voltage	2		5	2						
	Lens Operning (f stop)	2		5	2						
b) T.V. Electronic	Voltage In	2		5	2						
c) T.V. Xmitter	Voltage In	2		5	2						
	Wattage Out	2		5	2						
d) T.V. Antenna	Orientation	1		2	5						
Navigation	Attitude	3		.5							
	Vertical	1		.5							
	Angle	3		.5							
	x.y.z. Function	3		.5							
	Bearing Distance	1		.5							
	Computor Heading	1		.5							
	Acceleration	3		.5	unknown						
	Rates	3		.5							
	Distance	3		.5							
	Clock Rate	1		.5							

(1) System Function	(2) Tenative Measurements	(3) Number Tent. Corr.	(4) Percent Accuracy	(5) Max Freq.	(6) Duty Cycle	(7) Wave Form	(8) Time V.S. Level Change	(9) Bi-Level	(10) Remarks	(11) Ref. No.
Life Support	Pressure in Air Tanks	3	2	2						
	Temperature	6	2	2						
	H_2O Content in Air	1	2	2						
	CO_2 Content in Air	1	2	2						
	N_2 Content in Air	1	2	2						
	O_2 Content in Air	1	2	2						
	Suit Temperature	8	2	2						
	Air Tank Valves	10	-	-				x		
	Fans	10	-	-				x		
	Temperature Conditioning	10	-	-				x		
	Air Lock Position	4	-	-				x		
Drive Train	R.P.M. of Motors	4	5	unknown						
	R.P.M. of Wheels	4	5	5						
	Motor Voltage	4	5	2						
	Motor Current	4	2	2						
	Motor Temperature	12	5	2						
	Acceleration	1	2	20						
	Direction of Heading	2	2	2						
	Applied Brake Pressure	4	5	2						
	Brake Temperature	8	5	2						
	Brake Set	4	-	-				x		
	Drive Wheel Selection	4	-	-				x		
	Wheel Lock	4	-	-				x		
	Center Position Lock	2	-	-				x		
	Gear Position	5	-	-				x		

(1) System Function	(2) Tenative Measurements	(3) Number Tent.	Corr.	(4) Percent Accuracy	(5) Max Freq.	(6) Duty Cycle	(7) Wave Form	(8) Time V.S. Level Change	(9) Bi-Level	(10) Remarks	(11) Ref. No.
Bio-Medical	Body Parameters	25		2							
Scientific Experiments											

1.2.2 DORMANT MODE

ANALYSIS OF MEASUREMENTS DORMANT MODE

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	MAX FREQ
Life Support	*Press. in Air Tanks	3	2	2
Nuclear Energy	*Voltage Out	2	5	2
	*Current Out	2	2	2
	Disintegration	10	5	10
	Temperature	30	2	2
Battery	*V.S. into Battery	3	2	2
	*V.S. from Battery	3	2	2
	*Temperature	9	2	2
	Voltage to Charg.	3	5	2
	Current to Charg.	3	5	2
	Volt. from Charg.	3	5	2
	Curr. from Charg.	3	5	2
Fuel Cells	*Output Voltage	3	5	2
	*Output Current	3	2	2
	*H_2+O_2 Level (Cry.)	6	5	2
	H_2+O_2 Press (Cry.)	6	5	2
	H_2+O_2 Flow (Gas)	6	5	2
	H_2+O_2 Press (Gas)	6	5	2
	H_2+O_2 Temp (Gas)	6	5	2
	*Cell Temp	3	5	2
	H_2+O_2 Valves	6	-	-
	H_2 Coolent Temp	3	2	2
Radiator	*Inlet Temp.	6	5	2
	*Outlet Temp.	6	5	2
	Δ Pressure	6	5	10
Potable H_2O	Temperature	3	5	2
	Pressure	3	5	2
	*Purity	3	2	2
	*Amount	3	5	2

*Vital

ANALYSIS OF MEASUREMENTS DORMANT MODE

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	MAX FREQ
Inverters	Voltage In	5	5	
	Current In	5	2	Dependent on
	*Voltage Out	15	5	Converter Used
	Current Out	15	2	
	Frequency Out	5	2	
	*Temperature	10	5	2
Converters	Voltage In	10	5	2
	Current In	10	2	2
	*Voltage Out	10	5	2
	Current Out	10	2	2
	*Temperature	20	5	2
Communication				
1. Signal Conditioner	*Voltage In	5	5	2
2. Encoder	*Voltage In	2	5	2
3. T/M Transmitter	Voltage In	2	5	2
	*Wattage Out	2	5	2
4. Television				
a. Vidicon	*Target Voltage	2	5	5
	Lens Opening	2	2	2
b. TV Electronics	*Voltage In	2	5	2
c. TV Tramsmitter	Voltage In	2	5	2
	*Wattage Out	2	2	2
d. TV Antenna	*Orientation	1	2	5
External Environment	Temperature	20	2	2
	Pressure	2	2	2
	Position of Vehicle	3	2	10

*Vital

SUMMARY OF DORMANT MODE

Total Number of Measurements	- 314
Total Number of Vital Measurements	- 126
Maximum Expected Accuracy	- 2%

Temperature Measurements	- 116
Voltage Measurements	- 66
Miscellaneous Measurements	- 55
Current Measurements	- 51
Pressure Measurements	- 26

NOTES: Additional measurements will be required during the initial landing and deployment. These measurements may consist of:

1. Ramp Position
2. Valve Position of Gas Lines
3. Position of Sun Tracker
4. Position of Star Tracker
5. Interconnection of Experiments & Power Supply

1.2.3 UNMANNED ROVING MODE

ANALYSIS OF MEASUREMENTS — UNMANNED ROVING MODE

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	MAX FREQ
Nuclear Energy Pwr.	Voltage Out	2	5	2
	Current Out	2	5	2
	Disintergration	10	5	10
	Temperature	30	2	2
Battery	V.S. into Battery	3	2	2
	V.S. from Battery	3	2	2
	Temperature	9	2	2
	Voltage to Charger	3	5	2
	Current to Charger	3	5	2
	Voltage from Charger	3	5	2
	Current from Charger	3	5	2
Fuel Cells	Output Voltage	3	5	2
	Output Current	3	2	2
	$H_2 + O_2$ Level (cry)	6	5	2
	$H_2 + O_2$ Temp (cry)	6	5	2
	$H_2 + O_2$ Press (cry)	6	5	2
	$H_2 + O_2$ Press (gas)	6	5	2
	$H_2 + O_2$ Temp (gas)	6	5	2
	Cell Temp	3	2	2
	$H_2 + O_2$ Valve Closure	6	-	-
Radiator	Inlet Temp	6	5	2
	Outlet Temp	6	5	2
	ΔPressure	6	5	10
Inverters	Voltage In	5	5	Dependent on
	Current In	5	2	inverter type
	Voltage Out (3ϕ)	15	5	
	Current Out (3ϕ)	15	2	
	Freq Out (3ϕ)	15	2	
	Temperature	10	5	

ANALYSIS OF MEASUREMENTS UNMANNED ROVING MODE

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	MAX FREQ
Converters	Voltage In	10	5	2
	Current In	10	2	2
	Voltage Out	10	5	2
	Current Out	10	2	2
	Temperature	20	5	2
Communications				
1. Signal Conditioner	Voltage In	5	5	2
2. Encoder	Voltage In	2	5	2
3. T/M Transmiter	Voltage In	2	5	2
	Wattage Out	2	5	2
4. Television				
a Vidicon	Position (external)	2	2	5
	Lens Opening (f stop)	2	5	2
b T.V. Eletronics	Target Voltage	2	5	2
c. T.V. Transmitter	Voltage In	2	5	2
	Wattage Out	2	5	2
d. T.V. Antenna	Orientation	1	2	5
Drive Train	RPM of Motors	4	5	unknown
	Current to Motors	4	5	5
	Voltage to Motors	4	5	2
	Temp. of Motors	12	2	2
	RPM of Wheels	4	5	2
	Acceleration	1	2	20
	Direction of Heading	2	2	2
	Brake Pressure	4	5	2
	Brake Temp.	8	5	2
	Brake Set	4	-	-
	Drive Wheel Select.	4	-	-
	Wheel Lock	4	-	-
	Center Position	2	-	-
	Gear Position	5	-	-

ANALYSIS OF MEASUREMENTS

UNMANNED ROVING MODE

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	MAX FREQ
Navigation	Attitude	3	.5	unknown
	Vertical	1	.5	
	Angle	3	.5	
	x,y,z Function	3	.5	
	Bearing Distance	1	.5	
	Computor Heading	1	.5	
	Acceleration	3	.5	
	Rates	3	.5	
	Distance	3	.5	
	Clock Rate	1	.5	
External Environment	Temperature	20	2	
	Pressure	2	2	
	Position	3	10	

SUMMARY OF UNMANNED ROVING MODE

Total Number of Measurements	- 389
Maximum Expected Accuracy	- 0.5%
Temperature Measurements	- 136
Miscellaneous Measurements	- 106
Voltage Measurements	- 68
Current Measurements	- 55
Pressure Measurements	- 24

NOTES: During the unmanned roving mode, maximum use will be made of television, navigation aids, and any terrain sensing devices. Bio-medical, life support, and scientific measurements will not be telemetered during this mode.

1.2.4 MANNED ROVING MODE

ANALYSIS OF MEASUREMENTS **MANNED ROVING MODE**

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	SAMPLE RATE
Life Support	Pressure in Air Tanks	3	2	2
	Temperature	6	2	2
	H_2O Content in Air	1	2	2
	CO_2 Content in Air	1	2	2
	N_2 Content in Air	1	2	2
	O_2 Content in Air	1	2	2
	Suit Temperature	8	2	2
	Air Tank Valves	10	-	-
	Fans	10	-	-
	Temp. Conditioning	10	-	-
	Air Lock Position	4	-	-
Drive Train	RPM of Motors	4	5	Unknown
	RPM of Wheels	4	5	5
	Motor Voltage	4	5	2
	Motor Current	4	2	2
	Motor Temperature	12	5	2
	Acceleration	1	2	20
	Direction of Heading	2	2	2
	Applied Brake Pressure	4	5	2
	Brake Temperature	8	5	2
	Brake Set	4	-	-
	Drive Wheel Selection	4	-	-
	Wheel Lock	4	-	-
	Center Position Lock	2	-	-
	Gear Position	5	-	-
Nuclear Energy Power	Voltage Out	2	5	2
	Current Out	2	2	2
	Disintegration	10	5	10
	Temperature	30	5	2
Battery	V.S. into Battery	3	2	2
	V.S. from Battery	3	2	2
	Temperature	9	2	2
	Voltage to Charger	3	5	2
	Current to Charger	3	5	2
	Voltage from Charg.	3	5	2
	Current from Charg.	3	5	2

188

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	SAMPLE RATE
Fuel Cells	Output Voltage	3	5	2
	Output Current	3	2	2
	H_2+O_2 Levels (cry)	6	5	2
	H_2+O_2 Press. (cry)	6	5	2
	H_2+O_2 Flow. (gas)	6	5	2
	H_2+O_2 Press. (gas)	6	5	2
	H_2+O_2 Temp. (gas)	6	5	2
	Cell Temperature	3	2	2
	H_2+O_2 Valve Closure	6	-	-
	H_2 Coolent Temp.	3	5	2
Radiator	Inlet Temp	6	5	2
	Outlet Temp	6	5	2
	Δ Pressure	6	5	10
Inverters	Voltage In	5	5	
	Current In	5	2	
	Voltage Out (3ϕ)	15	5	freq dependent on inverter type
	Current Out (3ϕ)	15	2	
	Frequency Out (3ϕ)	15	2	
	Temp.	10	5	2
Converters	Voltage In	10	5	2
	Voltage Out	10	2	2
	Current In	10	5	2
	Current Out	10	2	2
	Temperature	20	5	2
Communications				
1. Signal Conditioner	Voltage In	5	5	2
2. Encoder	Voltage In	2	5	2
3. T/M Transmitter	Voltage In	2	5	2
	Wattage Out	2	5	2
4. Television				
a. Vidicon	Position	2	2	5
	Lens Opening	2	5	2
b. Electronics	Voltage In	2	5	2
c. Transmitter	Voltage In	2	5	2
	Wattage Out	2	5	2
d. Antenna	Orientation	1	2	5

ANALYSIS OF MEASUREMENTS UNMANNED ROVING MODE

SYSTEM DIVISION	MEASUREMENT	NUMBER	% ACCURACY	MAX FREQ
Navigation	Attitude	3	.5	
	Vertical	1	.5	
	Angle	3	.5	
	x.y.z. Functions	3	.5	unknown
	Bearing Distance	1	.5	
	Computor Heading	1	.5	
	Acceleration	3	.5	
	Rates	3	.5	
	Distance	3	.5	
	Clock Rate	1	.5	
External Environment	Temperature	20	2	
	Pressure	2	2	
	Position	3	10	
Bio-Medical	Body Parameters	25	2	
Potable H_2O	Temperature	3	5	2
	Pressure	3	5	2
	Amount	3	5	2
	Purity	3	2	2

SUMMARY OF MEASUREMENTS USED IN ROVING MODE

Total Number of Measurements	- 475
Maximum Accuracy Required	- 0.5%

Miscellaneous Measurements	- 162
Temperature Measurements	- 160
Voltage Measurements	- 68
Current Measurements	- 55
Pressure Measurements	- 30

NOTES: During the manned mode many scientific experiments will be conducted that will not require telemetry. Some proposed instrumentation will acquire a tape recorder as an aid in data collecting. The manner in which this data will be handled has not yet been defined.

A proposal has been made to rely on television for the transmission of some scientific data which is the form of notes, pictures, and graphs.

1.3 SCIENTIFIC INSTRUMENTATION

1.3.1 INTRODUCTION

The scientific instrumentation has been divided into two phases -- the dormant MOLAB mode, which is called the embryonic emplaced instrument complex (EEIG), and the roving mode or full emplaced instrumented complex. In the succeeding pages, a sketch and description is given for each instrument currently considered for the (EEIG). No attempt has been made at this time to collate this data into a conceptual system nor has a breakdown sheet been generated due to the diverse nature of the experiments.

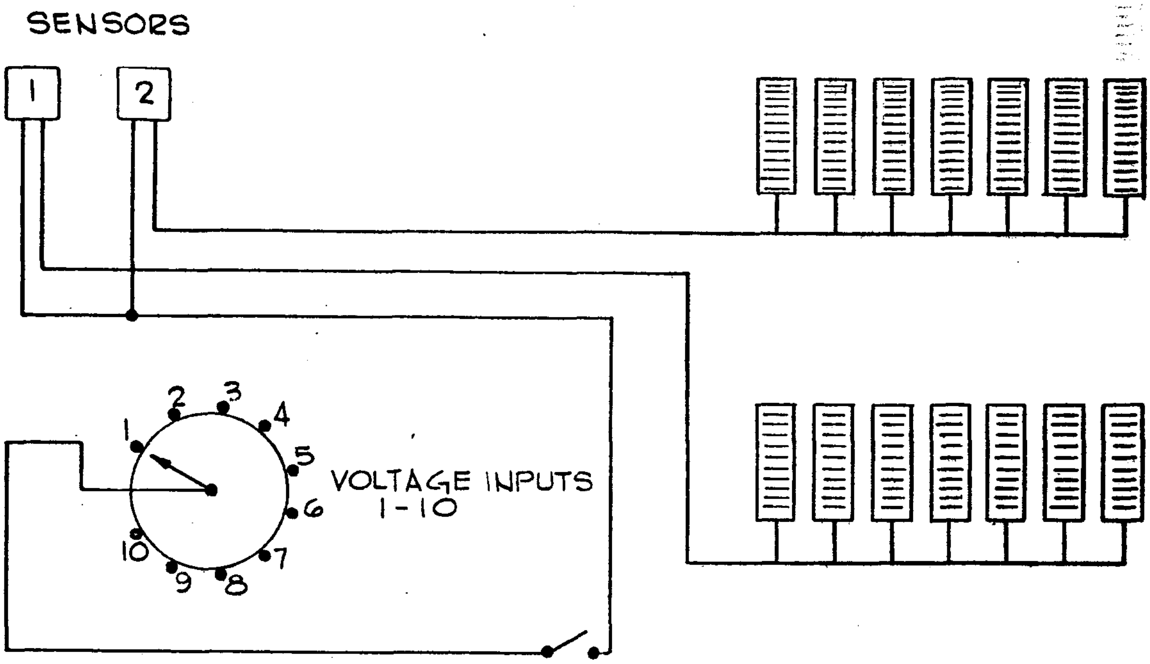
The present philosophy is to incorporate a data compression device into the system to provide continuous coverage of phenomena.

1.3.2 SCIENTIFIC INSTRUMENTATION PACKAGES

1.3.2.1 Solar Plasma Spectrometer

This instrument has two sensors which change their sensitivity in ten discrete steps as a function of ten sequentially applied voltages. Each voltage step is applied for one hour allowing the plasma count to accumulate on 14 decades (7 for each sensor) prior to readout and recording on magnetic tape. This occurs in less than one minute. After all ten voltages have been impressed the cycle repeats itself continuously. See figure 1-1.

SOLAR PLASMA SPECTROMETER



NOTES:
ONE SENSOR WILL BE SUN-TRACKED
REQUIRES CONTINUOUS COVERAGE
SAMPLES TAKEN ONCE/HOUR
READOUT < 1 MINUTE
ACCURACY REQUIRED = 5%

FIGURE 1-1

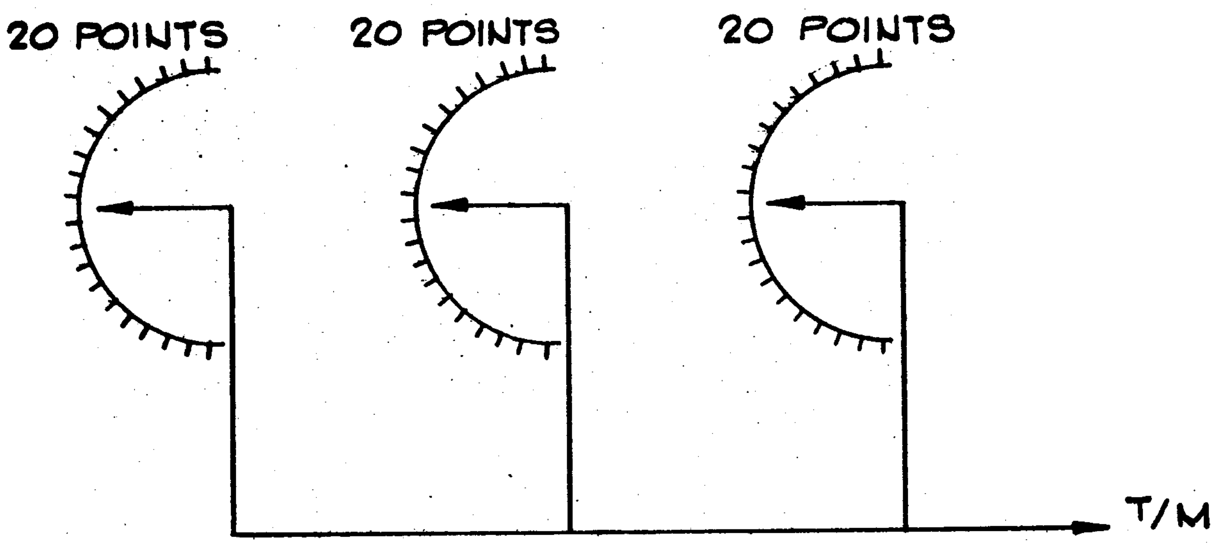
1.3.2.2 Charged Particle Spectrometer

The charged particle spectrometer sensor is coupled to a spectrum analyzer that contains three 20-point segments, giving a total resolution of 60 points. Each of these points will have a value of either zero or five volts and will be sampled sequentially. The analyzer will accumulate its count for ten minutes, readout will occur within one minute, and the analyzer will be reset to start the next accumulation. During this time the sensors are tracking the sun. The readout is to be tape recorded in time sequence with other instrumentation. See Figure 1-2.

1.3.2.3 Neutron Phoswich

The sensors of this instrument track the sun and, in turn, energize three decades, each of which will assume a voltage between zero and five volts d.c. as a function of the accumulated count. These decades will be read out sequentially after allowing three hours for the count to accumulate. The readout time will be less than one minute and will be time sequenced recorded with other scientific instrumentation. See Figure 1-3.

CHARGED PARTICLE SPECTROMETER

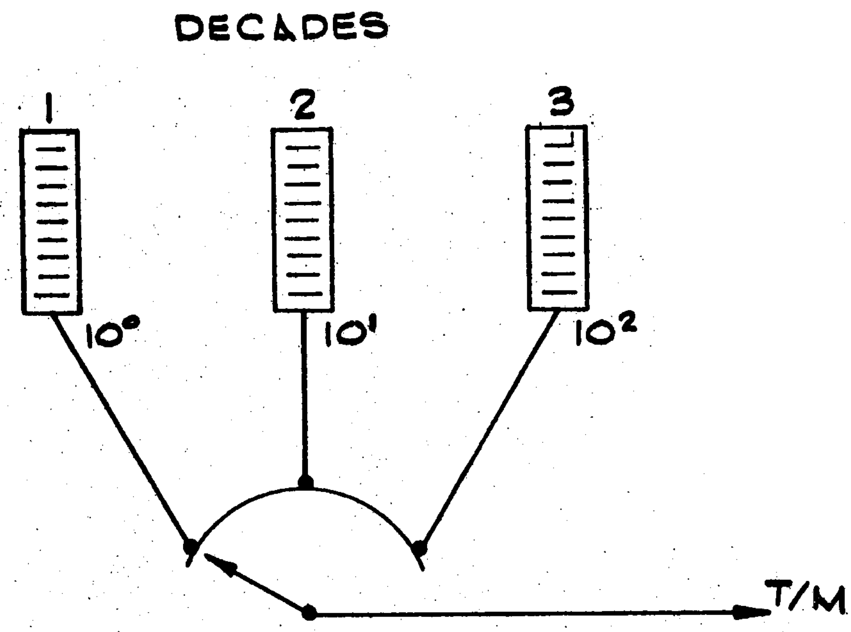


OUTPUT FROM 3 20POINT SEGMENTS OF A
SPECTRUM ANALYZER

NOTES:
EACH POINT WILL HAVE A VALUE OF EITHER 0 OR 5 V. DC
POINT TO BE SAMPLED SEQUENTIALLY
THE ANALYZER WILL ACCUMULATE FOR 10 MINUTES
READOUT < 1 MINUTE
ACCURACY REQUIRED = 5%
SENSORS WILL BE SUN-TRACKED

FIGURE 1-2

NEUTRON PHOSWICH



3 DECADES TOTAL COUNT = 999

NOTES:
READOUT CONSISTS OF SAMPLING THE THREE DECADES SEQUENTIALLY
EACH DECADE WILL HAVE A VOLTAGE BETWEEN 0-5 VDC
ACCUMULATION OF COUNT WILL BE 3 HOURS
READOUT < 1 MINUTE
ACCURACY REQUIRED = 2%
SENSORS WILL BE SUN-TRACKED

FIGURE 1-3

1.3.2.4 Gamma Ray Detector

The sensors for this instrument will energize three decades which will assume a voltage valve between zero and five. After one hour count accumulation time, a sequential readout of the decades will be converted to an 8 bit binary code. Five bits of information will be used for decade resolution and 3 bits will accomplish scaling. This readout time is to be less than one minute and will be time sequenced tape recorded. See Figure 1-4.

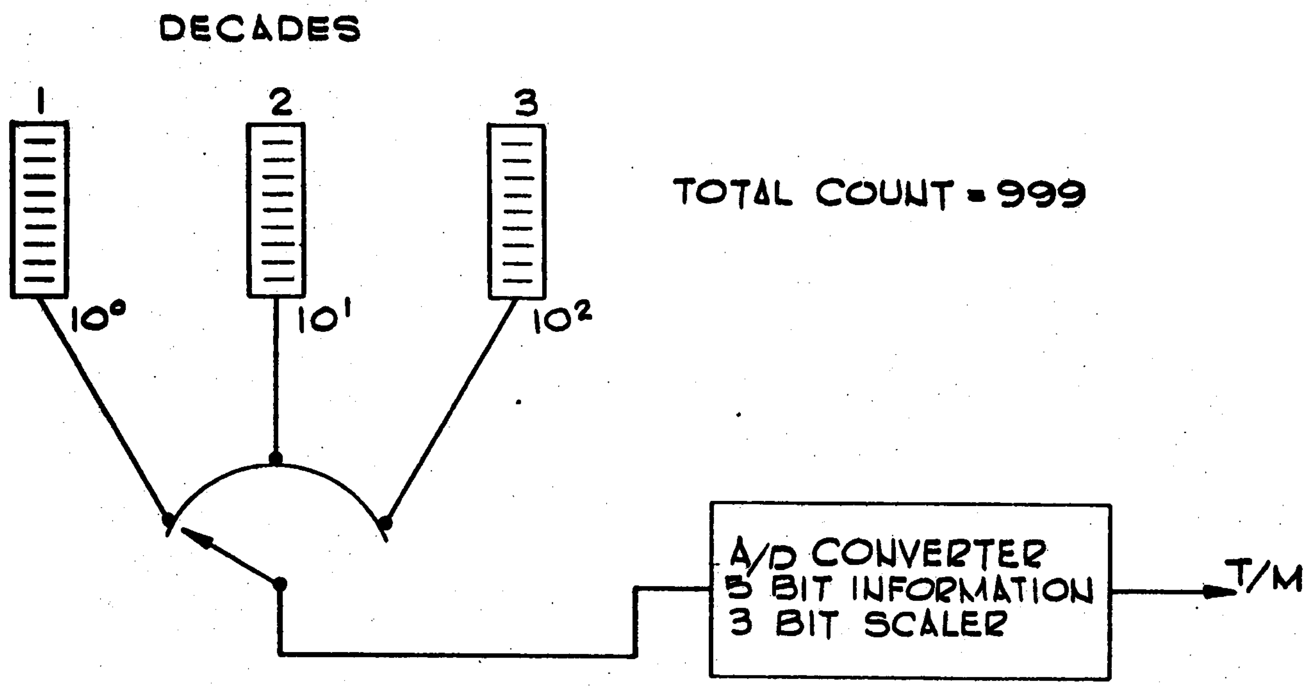
1.3.2.5 Total Gas Pressure

This instrument will measure the total gas pressure found on the lunar surface. The output from the sensor will be a quasi-static d.c. voltage between zero and five volts that will equate the pressure. A reading of this instrument will occur once an hour and will be recorded in time sequence on tape after the gamma ray count. See Figure 1-5.

1.3.2.6 Electric Field Strength

This instrument employs two sensors located at different heights above the lunar surface. Each sensor will produce a quasi-static voltage reading between zero and five volts. During the hourly readout the two sensors will be tape recorded in sequence. This recording is to follow the total gas pressure. See Figure 1-6.

GAMMA RAY DETECTOR

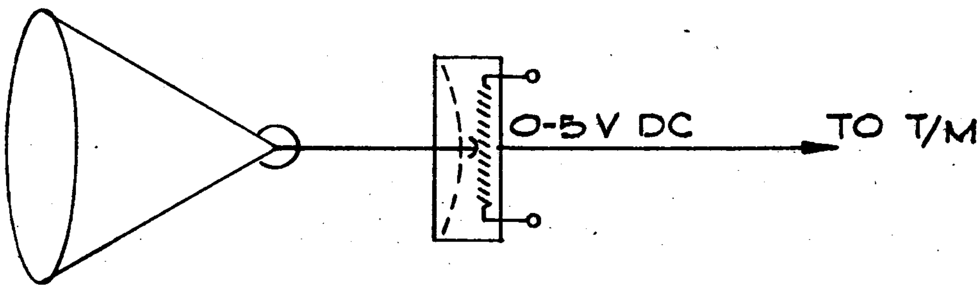


5 BITS FOR INFORMATION READOUT EACH DECADE
3 BITS FOR SCALING

NOTES:
INSTRUMENT A 3 SLOT COUNTER
ACCUMULATION TIME ONE HOUR
READOUT < 1 MINUTE
5 BITS DEVOTED TO RESOLVING COUNT
3 BITS DEVOTED TO SCALING COUNTER
ACCURACY REQUIRED = 2% (WILL ACCEPT LESS)

FIGURE 1-4

TOTAL GAS PRESSURE

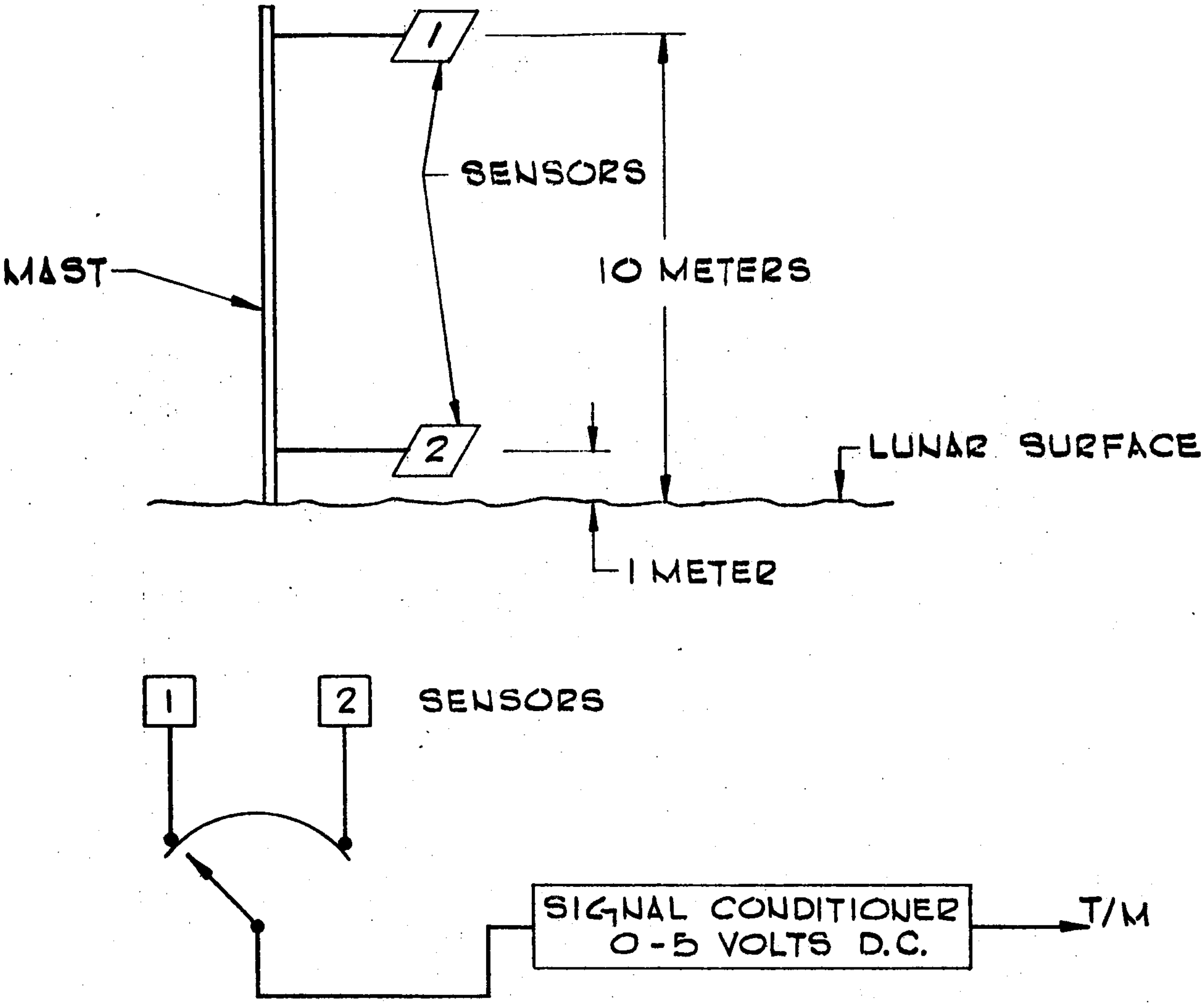


STATIC DC READING

NOTES:
OUTPUT IS BETWEEN 0-5 V DC
READING IS STATIC
SAMPLE WILL OCCUR ONCE AN HOUR
ACCURACY REQUIRED = 5%
RECORDED AFTER GAMMA RAY COUNT

FIGURE 1-5

ELECTRIC FIELD STRENGTH



NOTES
OUTPUT WILL BE A STATIC 0-5 V D.C.
READOUT WILL OCCUR ONCE AN HOUR
ACCURACY REQUIRED = 5%
TO BE RECORDED AFTER TOTAL GAS PRESSURE

FIGURE 1-6

1.3.2.7 Charged Dust Detector

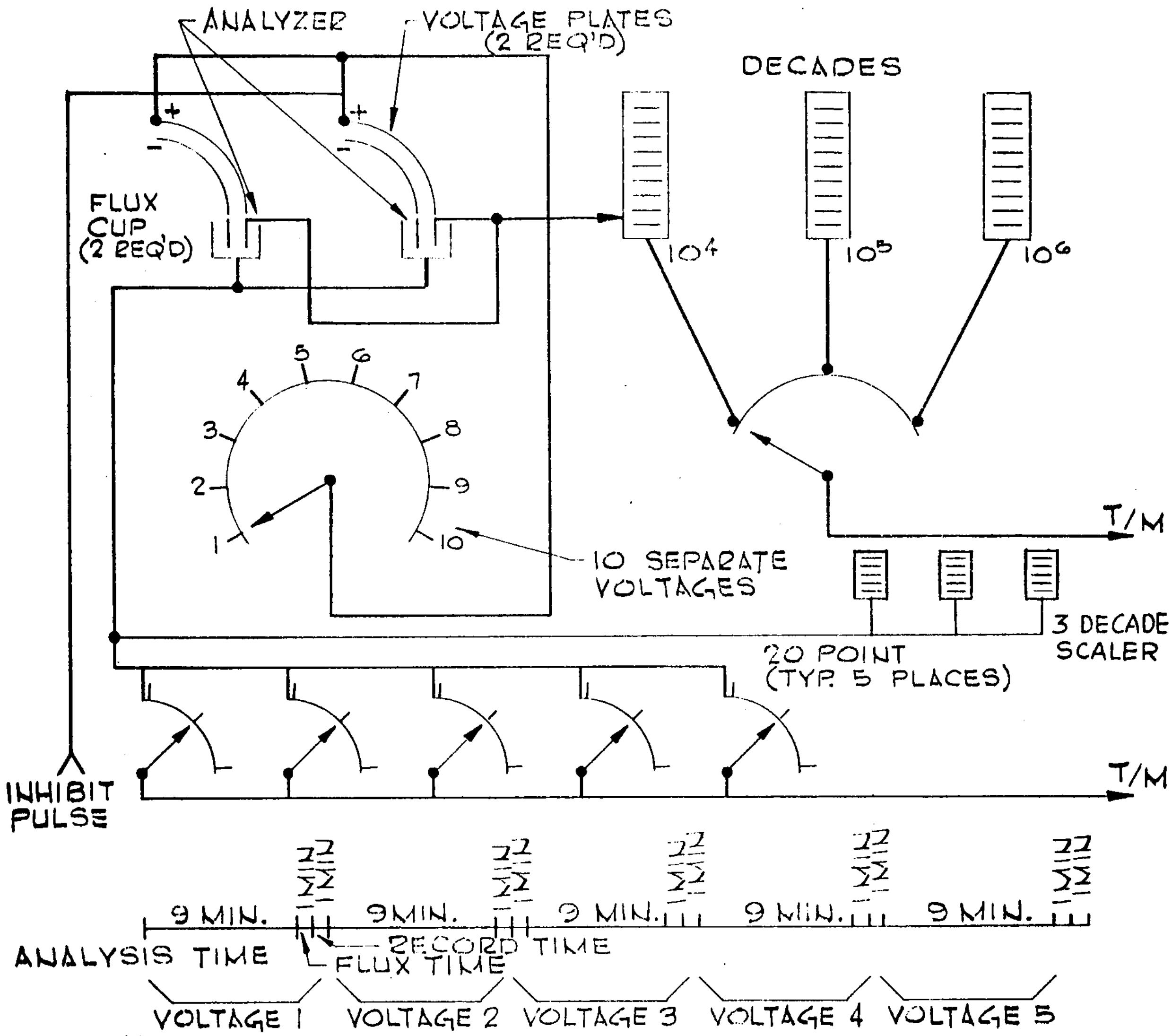
This complete instrument performs two basic functions in the detection of dust particles: 1) it measures the velocity of the particle and 2) it measures the total number of particles that enter the sensors within a prescribed time (flux density). These two functions are performed with 10 different voltages being applied in a sequential manner to the sensors.

The sequence starts with a nine-minute period of velocity analysis at one of ten voltage settings. During this time period the velocity of an individual particle will be sensed by the analyzer plates. Instrumentation will display the computed velocity on three decades which will assume a voltage between zero and five volts. Once a particle has entered the sensors, an inhibit pulse will be generated to prevent subsequent particles that may enter the sensors from giving an erroneous reading. This inhibit pulse will continue until the transit time has been computed and recorded on tape. The inhibit time will be commensurated with the frequency capability of the telemetry system.

After nine minutes the velocity analyzers and the inhibit circuitry will become inoperative, allowing a flux measuring time of one minute. The flux accumulation will be displayed on five 20-point pulse analyzers which will be readout in sequence within one minute following the flux measuring time.

The above process will be repeated for each of the ten voltage settings, and then will be recycled. See Figure 1-7.

CHARGED DUST DETECTOR



NOTES:
ANALYSIS CONSISTS OF RECORDING SPEED OF DUST PARTICLE
ONLY 3 MOST SIGNIFICANT DECADES WILL BE READ
INHIBIT PULSE WILL PREVENT ADDITIONAL PARTICLES FROM DESTROYING COUNT
READOUT OF SPEED ANALYZER DURING INHIBIT (MAX. 30 SECONDS)
CONTINUOUS RECORDING
FLUX DENSITY WILL ACCUMULATE ON 5 20 POINT PULSE HEIGHT ANALYZERS (0 - 5 V D.C.)
READOUT IN 1 MINUTE (MAX.)
ACCURACY REQUIRED = 5%

FIGURE 1-7

1.3.2.8 Atmosphere Mass Spectrometer

The sensors of this instrument are coupled to a one thousand (1,000) slot pulse-height analyzer, each of which will assume a voltage of zero or five. The analyzer will accumulate a count for one hour, then readout will be performed on all slots within one minute. The output is to be tape-recorded in time sequence. See Figure 1-8.

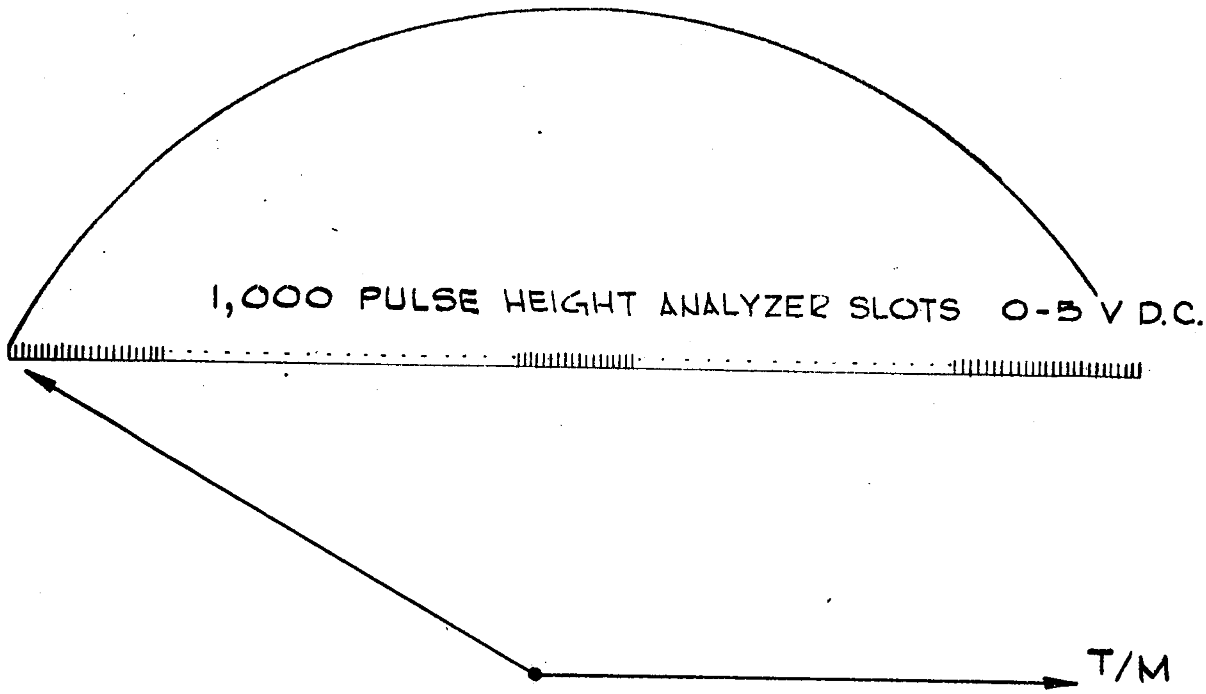
1.3.2.9 Lunar Quake Seismometer

The design of this instrument has not been detailed; however, a continuous recoding is desired with an accuracy of five percent. See Figure 1-9.

1.3.2.10 Meteoroid Detector

This instrument employs two sensors (microphones) which are located on the outer surface of the MOLAB. Meteorite impacts are sensed and counted on six decades (three for each sensor) which will assume a voltage between zero and five volts. Each sensor and associated decades will accumulate a count for one hour, then will be read out sequentially within one minute. The output will be tape-recorded in time sequence with other scientific data. See Figure 1-10.

ATMOSPHERE MASS SPECTROMETER



NOTES:
TOTAL "SLOT" NUMBER WILL BE APPROXIMATELY 1,000
EACH SLOT WILL HAVE A VOLTAGE OF 0-5 V D.C.
ACCUMULATION TIME TO BE 1 HOUR
READOUT WILL OCCUR < 1 MINUTE
ACCURACY REQUIRED = 5%

FIGURE 1-8

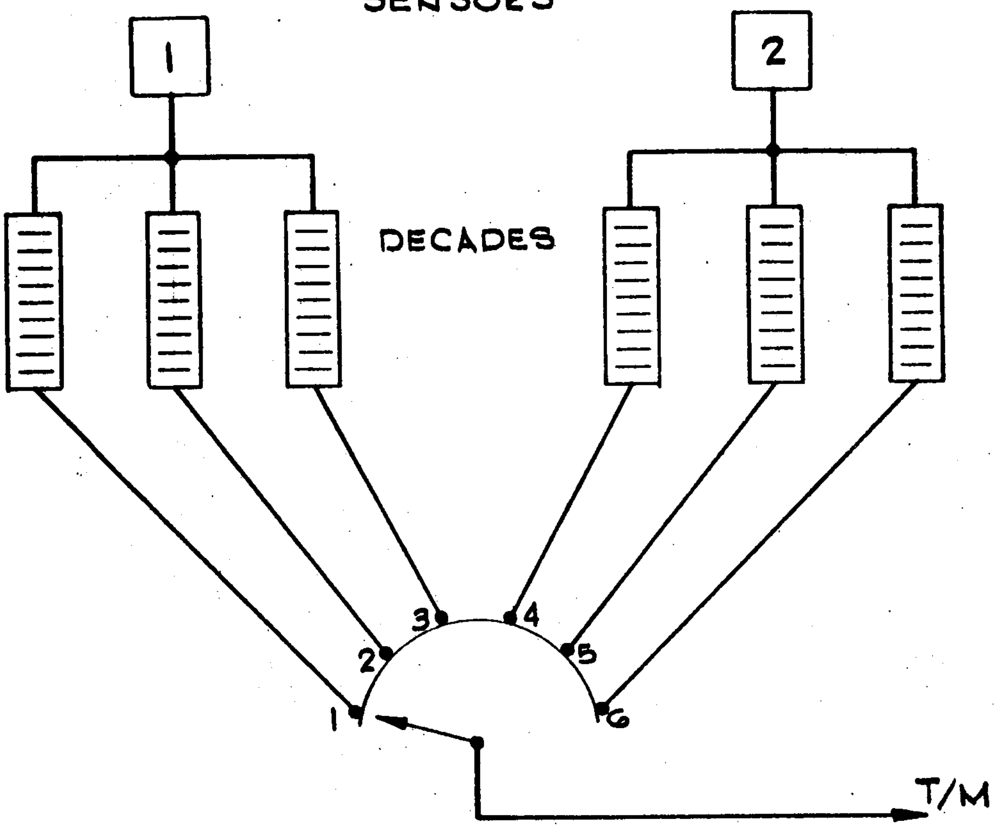
LUNAR QUAKE SEISMOMETER

NO CONCEPT
TO DATE

NOTES:
4 SENSORS
10 CYCLES PER SECOND MAXIMUM FREQUENCY
ACCURACY REQUIRED = 5%
CONTINUOUS RECORDING REQUIRED

FIGURE 1-9

METEOROID DETECTOR



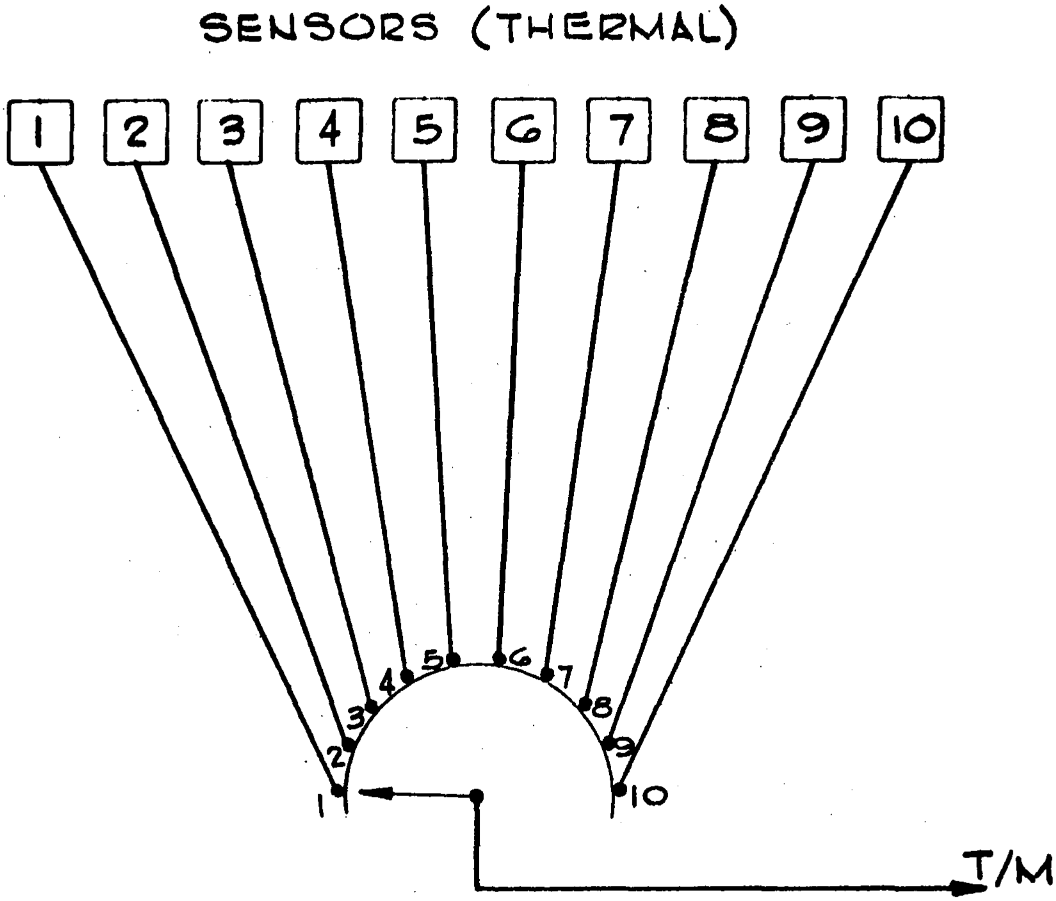
NOTES:
2 DETECTORS (SENSORS) ARE USED
ACOUSTICAL TYPE SENSORS (1 ON SIDE, 1 ON TOP OF MOLAB)
ACCUMULATION TIME WILL BE 1 HOUR
READOUT TIME WILL BE LESS THAN 1 MINUTE
6 DECADES WILL BE READOUT SEQUENTIALLY
OUTPUT VOLTAGE 0-5 V D.C.
ACCURACY REQUIRED = 5 %

FIGURE 1-10

1.3.2.11 Material Surface Degradation

Ten samples of various types of surfaces will be exposed on the lunar surface during the dormant period. Each sample will have a temperature sensing device affixed. Upon command from the earth controlling station, the temperatures will read sequentially. All readings will be quasi-static d.c. voltages. See Figure 1-11.

MATERIAL SURFACE DEGRADATION



NOTES:
MEASUREMENT CONSISTS OF THERMAL READINGS
10 SURFACES WILL BE EXAMINED
0-5 VOLT OUTPUT FROM EACH SENSOR
STATIC READING (SEQUENTIALLY)
NOT RECORDED DATA - INTERROGATED BY D.S.I.F.
ACCURACY REQUIRED = 5%

FIGURE 1-11

2.0 TRANSDUCERS

The accuracy of any telemetry system must, through necessity, start with the transducers. It is in the transducers that the accuracy and the resolving power of the system blend together to provide the needed data.

The classification of transducers can be defined broadly according to the function they perform and the operating method. The function classification is readily sub-divided into (1) the checkout and control measurements and (2) the specialized scientific measurements. The former classification (checkout and control) is represented by the transducers used for measuring such parameters as:

a) Pressure
b) Temperature
c) Strain
d) Flow
e) Voltage
f) Current
g) Acceleration
h) Etc.

The transducer for specialized scientific parameters is somewhat more exotic and does not lend itself to specific cataloging.

The operating methods of transducer transcends many functions and are applied according to the range, size, weight, accuracy, resolution, and the environmental conditions that must be met. The bulk of the transducers operate by using one of the following methods:

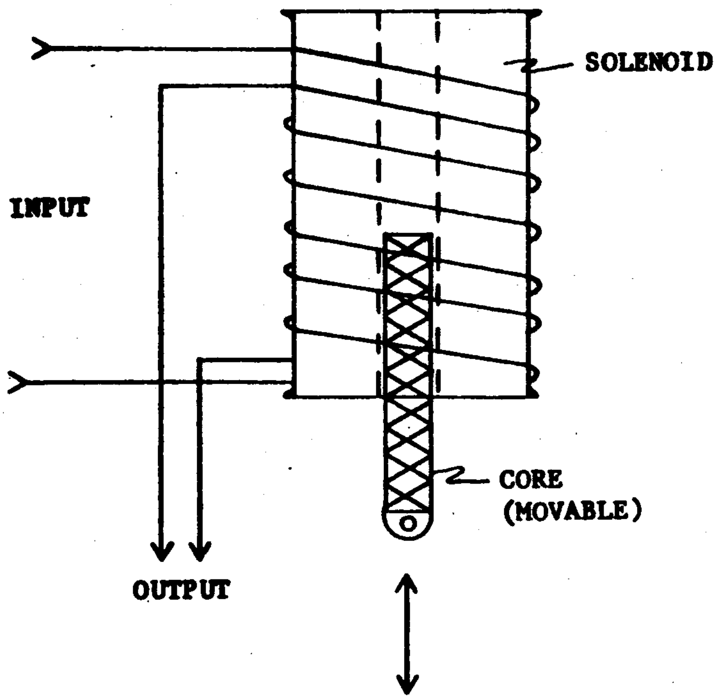
a) Resistance changing
    1) bridge
    2) potentiometric
b) Inductance
c) Capacitance
d) Thermocouple thermister
e) Piezoelectric

Further delineation of the methods include the self-generating instruments and those that must work in conjunction with some type of signal conditioning device. Some excellent examples of self-generating transducers are voltage-divider networks, current shunts, and thermocouples.

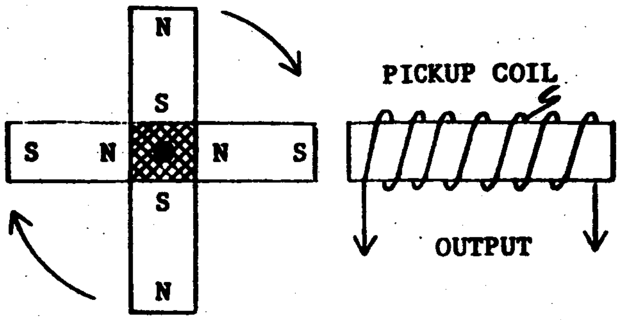
The actual operating mechanics of the more commonly used instruments are noted:

Inductance Circuit

Typical Use	Pressure, Position, Flow, Level
Advantages	No physical contact required
Disadvantages	More complex, weight and size greater, may require an a.c. voltage source



POSITION PRESSURE CIRCUIT



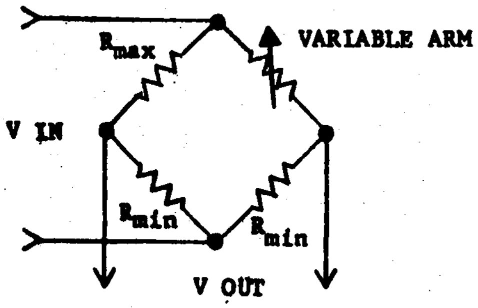
FLOW CIRCUIT

Bridge Circuit

Use — Thermister (temperature) and strain

Advantages — Simple, lightweight, small size, low hysterises

Disadvantages — Temperature sensitive, frangible, needs amplification



A simple voltage calculation for input voltage is as follows:

$$Vin = Vout \frac{K^2+(1+Rmax/Rmin)K+Rmax/Rmin}{(Rmax/Rmin-1)K}$$

where

Vout = required voltage out
Vin = required voltage in
K = Resistance ratio of bridges high arms to the minimum resistance of circuit.

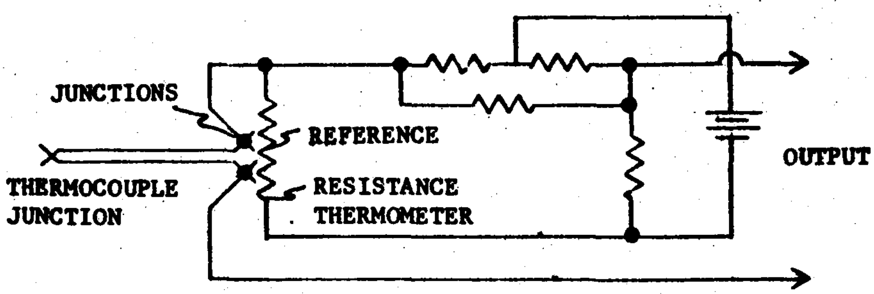
Thermocouple Circuit

Typical Use — Temperature measurements

Advantages — Lightweight, reliable, wide range, self-generating.

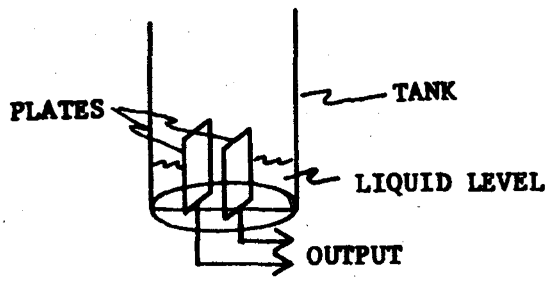
Disadvantages — Must be temperature compensated, thermal lag, non-linear output.

NOTE: In sketch below, one type of compensating circuit is used.



Capacitance Circuit

Typical Uses	Pressure, Position, Level
Advantages	No contact required, sensitive
Disadvantages	Calibration difficulties, requires signal conditioning



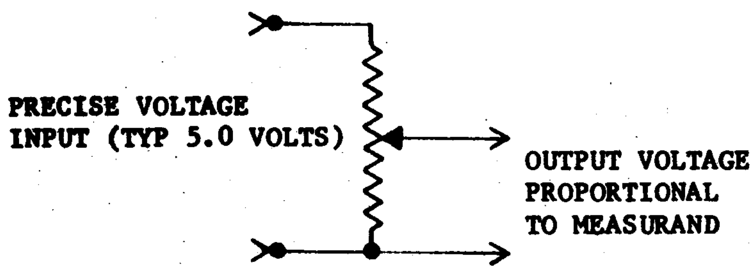
LEVEL SENSOR METHOD

Piezoelectric

Typical Uses	Acceleration, Vibration
Advantages	High output, simple, lightweight
Disadvantages	Nonlinear output, temperature sensitive.

Potenteometric Circuit

Typical Use	Pressure, Position
Advantages	Simplicity, requires little or no signal conditioning
Disadvantages	Subject to drag of wiper arm (hysterises), vibration, and non-repeatability
Notes	The wiper arm may be actuated by any one of several methods such as bellows, positioning arm, diaphragm, etc.



The ratings of pressure transducers are given in the maximum range and, as such, the resolution and the total error must be equated for each measurement.

$$R = P_{max} \cdot E_t$$

where

R = Resolution of the gage

P_{max} = Maximum pressure rating of the gage

E_t = Total error of the gage (temperature drift, hysterises, non-linearity, etc.)

Since in many instances the expected pressure may be quite high, but will vary a few percent within this predetermined level, the application of a differential or biased (expanded scale) absolute gage will be more apt to give the needed resolution.

An analysis of the current pressure gages shows that many different approaches have been made to measure this parameter, including potentiometric, planar diffused, variable reluctance, and strain gage. While no one gage is the optimum for the MOLAB mission, certain characteristics are desirable such as light weight, accuracy, and large range. Unfortunately, since these attributes are not combined, a compromise or tailor-fitting is necessary. As an example, for a light weight, an appreciable accuracy, and a low range, the variable reluctance gage seems to offer the best performance.

When measurements call for a higher range and greater accuracy, the strain gage principal is favored. The light weight, however, must be considered in view of the necessary signal conditioners which both of the above gages require. In the case of the variable reluctance system, an additional requirement of providing an a.c. supply (approximately 20 kc) is necessary for operation.

The potentiometric type of pressure gage has an advantage in the fact that no ancillary equipment is needed prior to insertion in the encoding portion of the telemetry system. This is excluding a stable voltage supply (usually 5.0 volts) that can -- and generally does -- supply more than one transducer. In relation to the MOLAB, where the vibration will not be a major factor in the selection of the transducers, this type of gage offers the simplicity and reliability not found in other types of sensors.

A trade off can be made between the potentiometric and the more complex methods when consideration is given to the following table which has been normalized to a single range of 0-100 psi.

	Potentiometric	Strain
Weight of transducer only	226 grams	8 grams
Weight of ancillary equipment	-	200 grams*
Accuracy	3.2%	1.5% **
Vibration susceptibility	0.03%	-
Complexity	no	yes

* DC signal conditioner amplifier = 0 - 5 volts output
** Summation of transducer and amplifier accuracy

The selection of the strain gage type was made as a representative sample of those requiring additional hardware versus the potentiometric type which does not. It should be noted, however, that for the purpose of isolation in some critical circuits, amplifiers are sometimes incorporated into the high level signal circuit. Conversely, low level commutation has the ability to sample the low level output of a strain gage, and to use a single amplifier after commutation prior to insertion into the system. This method can lead to some undesirable side effects.

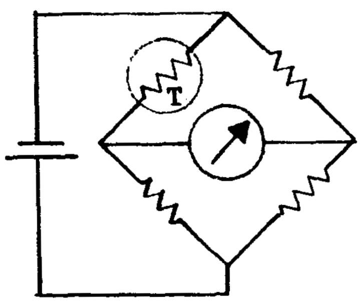
Other functions (acceleration, position, strain, flow, etc.) fall into similar conditioning problems of pressure gages. In summary, the value of the simple direct output from a potentiometric device should be considered as the first choice if the accuracy and range requirements do not warrant going to the more sophisticated methods.

A large percentage of the measurements to be made on the MOLAB are temperatures. The most common method of measurement is the use of dissimilar metals bonded together at one point, called the thermal junction. This device generates an EMF which is proportional to the temperature of that junction. The more useful combinations are iron/constantan, copper/constantan, chromel/alumel, and platinum/rhodium. A particular combination is selected on the basis of the temperature range to be measured and the environment in which it is to be used. Since the thermocouple output is also a function of the terminus, compensation must be achieved by additional circuitry. A simple method is to place a reference junction at some known temperature and calculate the measurand from this known reference. With the necessity for an inflight reference that can be maintained over an extended period of time, a variable reference system is used for compensation. The basic configuration of this circuit consists of a thermistor to which the reference junction is attached. This forms a partial arm of a bridge circuit which automatically compensates for temperature over an appreciable range.

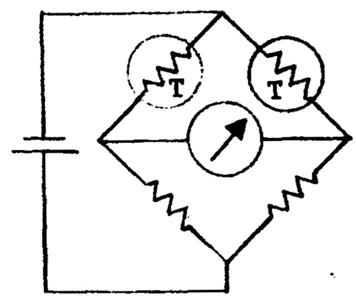
The voltage output for various combinations is very low, as can be seen in the table given below which has been normalized to a reference temperature of 0° C. The figures are in millivolts.

sent through the thermistor must be kept below a minimum threshold so that internal heat will not be generated in the body of the thermistor. Below this threshold a standard EI curve can be plotted against the external temperature of the unit. Two simple circuits are shown below -- one for measuring the absolute temperature, the other for measuring a temperature differential.

#1



#2



The resistance change of a thermistor may be several orders of magnitude per degree centigrade as compared with a platinum resistance bulb. The resolution and accuracy have been reported to be approximately 0.001^{o}F when coupled to a high gain stable amplifier; however, a realistic figure is about plus or minus 1/4 to 1/2 a degree C. in satellite applications. A limiting temperature of slightly more than 300^{o}C may prevent their use on some MOLAB equipment.

Additional applications of the thermistor can be summarized by noting the following proposed uses:

Temp. ^{o}C	Cu/Ct	Fe/Ct	Cr/Al	Pt/Rd
-100	-3.35	-4.82	-3.49	-----
0	0	0	0	0
100	4.28	5.40	4.10	.67
200	9.29	10.99	8.13	1.49
300	14.86	16.56	12.21	2.40
400	-----	22.07	16.39	3.40
500	-----	27.58	20.64	4.47
1000	-----	58.22	41.41	10.58

At the extreme ranges of all combinations the change in millivolts per degree becomes proportionally less, which results in a non-uniform accuracy over the entire range.

An undeniable advantage of the thermocouple as a means of ascertaining temperatures is the simplicity and the reliability of this type of sensor.

A more recent introduction into the field of temperature measurements is the thermistor. This device is a semiconductor of ceramic material made by sintering mixtures of metallic oxides such as uranium, cobalt, iron, copper, manganese, etc. The electrical characteristics are changed by combining these sintered oxides in varying ratios. The resistance of a thermistor is solely a function of its absolute temperature. For this reason the current

a) Time Delay

b) Power Measurements

c) Thermal Conductivity

d) Voltage Control

The variety of possible uses, plus the high delta R per degree centigrade, presents good possibilities of use on this program.

To summarize, the MOLAB requirements of extreme long life and reliability have not been previously encountered by transducer manufacturers. Therefore, an evaluation program must be started to provide information on acceptable transducers which will function in the hostile environment of the moon.

TYPICAL TRANSDUCERS

FUNCTION	OPERATIONAL METHOD	RANGE	REQ. V IN	V OUT F/S	ACCURACY	WEIGHT	MFG.	MODEL NO.
Pressure	Potentiometric	0-100	100 Max.	Proportional	3.2%	226 g	Fairchild	TP-300
Pressure	Planar diffused	0-100	10.0	.0025/V	2.0%	8 g	Fairchild	FPT-1
Pressure	Variable Rel..	0-30	5 @ 20KC	.150	2.0%	7 g	Hidyne	W series
Pressure	Strain gage	0-500	10	.004/V	1.0%	34 g	Std. Cont.	M 300
Acceler.	Piezoelectric	0-3.5kg	n.a.	.015/ Peak G	1.0%	15 g	Electra Sci.	6000
Position	Potentimetric	3/16-7/16	100 Max.	Proportional	2.0%	--	Bourns	141
Position	Variable Rel.	- 45	---	---	1.0%	226 g	Bourns	2203
Acceler	Potentiometric	- 50 G	---	Proportional	2.0%	226 g	Bourns	609

3.0 SIGNAL CONDITIONERS

A signal conditioner is a device that prepares a data signal for insertion into the multiplexing portion of the telemetry system. It is an all-inclusive name given to amplifiers, isolaters, and proportioners. The need for these units has grown as the complexity and size of the instrumentation packages have been increased. A partial list of the more common conditioners and their use is given below.

a) Direct Coupled DC Voltage Amplifier. (Single ended)

Characteristics: An economical amplifier that is primarily used for short term telemetry. Common mode rejection suffers, due to the mutual coupling of the input and output circuits. It has an advantage of a very sharp rise time, which is desirable in some types of high speed commutation.

Typical use: Strain gage, thermocouple, bridge circuit

b) Differential DC Voltage Amplifiers.

Characteristics: A more expensive and generally heavier unit designed for greater accuracy and long term drift application. This unit sometimes is chopper-stabilized to increase the input/output isolation and common mode rejection;

however, with this configuration, the commutation sampling rate is more limited, due to the lower rise time of the amplifier.

Typical use: Strain gage, thermocouple, bridge circuit

c) AC Amplifiers

Characteristics: An amplifier with a frequency response ranging from as low as 5 cps to greater than 20 kc, depending upon the need, manufacturing and cost.

Typical uses: Piezoelectric, variable reluctance, capacity units

d) Charge amplifiers

Characteristics: A more elaborate AC amplifier with high input capacitance that in effect negates the long wire capacitance from a remote sensor. Note: This is more apt to be the case if a centrally located signal conditioner is used.

Typical use: Piezoelectric

Although these conditioners constitute the major types in current use, the manner of employment and packaging varies widely from installation to installation. The initial approach is to place the signal conditioner adjacent to the end instrument requiring its function. An obvious advantage is the fact that the long transmission wires would carry only the high level data signals, resulting in a minimum signal loss and low noise. In some cases it is possible to use unshielded wire due to the high signal-to-noise ratio experienced with this method. (See Figure 3-1.) This method presents a greater weight factor, due to the necessity of the additional power cabling required for each remote module. If environmental control is to be exercised over the signal conditioners, an additional problem area is exposed because of the dispersed instrumentation. As an alternate to the remote location of each module, they can be situated in bank form, centrally located, with the low-level (or unwieldy) signals routed to them. Environmental control would be made considerably easier, and a reduction in the number of long power cables required to operate each individual remote module would result. (See Figure 3-2.) The penalty for this, of course, is the long, low-level signal lines which tend to indrease the signal-to-noise ratio at the input.

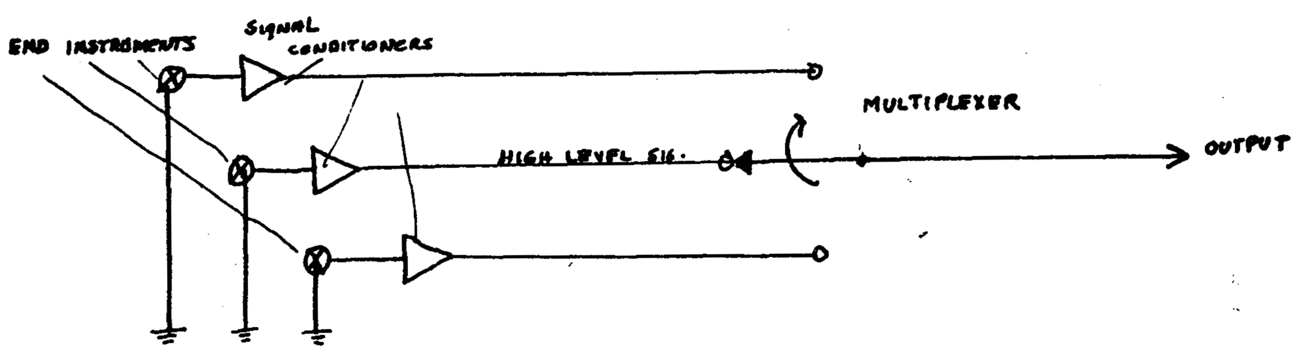


FIGURE 3-1 SIGNAL CONDITIONERS ADJACENT TO SENSORS

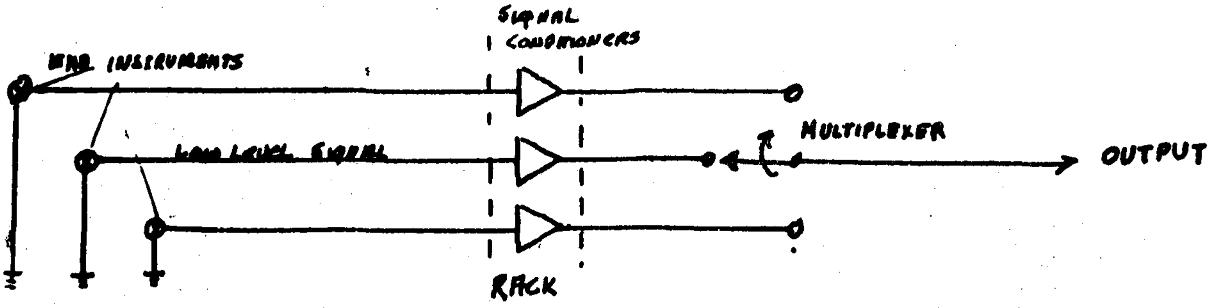


FIGURE 3-2 SIGNAL CONDITIONERS REMOTE FROM SENSORS

A third way, which in reality is an outgrowth of the previous method, is to package the individual modules in a "box" complete with power supplies, calibration facilities, and environmental control. Where relatively few signal conditioners are needed and the environmental aspects are of paramount importance, this approach offers a distinct advantage. (See Figure 3-3.)

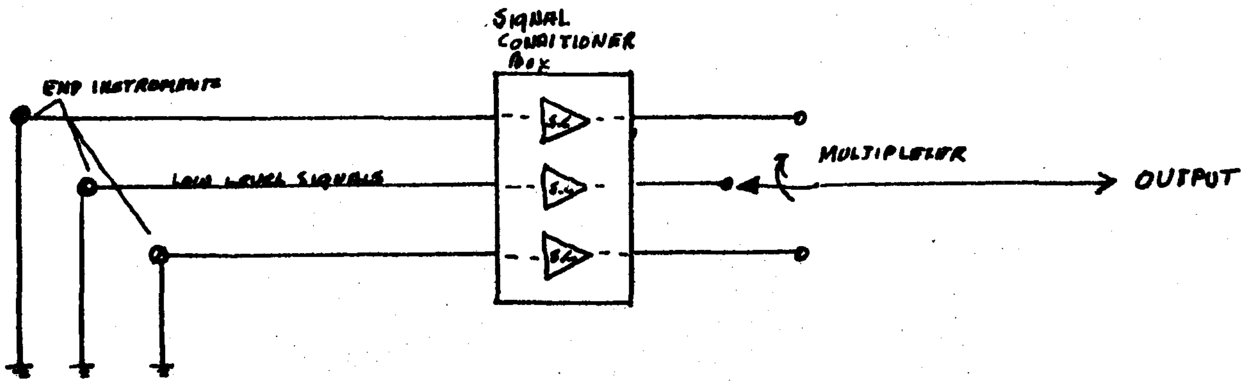


FIGURE 3-3 SIGNAL CONDITIONER BOX

A fourth technique that is adaptable to the more specialized cases, incorporates the conditioning device and the end instrument into a single package. Frequency conversion, digital formating, gyro/acceleration control packaging, and some scientific instrumentation, lend themselves to this approach. Where environmental conditions permit, this is an excellent method.

The acutal operation of the more unusual signal conditioners tends to illustrate the current state-of-the-art. For example, a chopper-stabilized amplifier using a differential input gives a high common mode rejection ratio. It operates by converting the DC input into an equivalent AC (via a flip-flop) which, in turn, is fed to an input transformer. This transformer gives the isolation and, as it is a differential device, only the delta V (signal) is induced into the secondary. Capacity coupling prevents the common mode rejection ratio from assuming an infinite value; however, by proper construction of the transformer, this effect can be reduced to give an overall ratio of about 10^6 to 1.

An application in the telemetry system may require the transmission of an approximately known frequency. Examples of this can be found in the cycles per second of an inverter, the clock rate of a digital system, the revolutions per second of a shaft, or any periodic re-occurring phenomenon which has a base in some known count. The telemetry bandwidth required for the transmission of raw data of this type is generally quite high. One method of conditioning is to change the measurand into an equivalent analog voltage ranging from 0-5 volts. Another method is to convert the basic frequency into a differential by using a stable local oscillator and hetrodyning. This latter method is more acceptable due to the much greater accuracy that can be realized. A block diagram, Figure 3-4, illustrates the salient points of this signal conditioner.

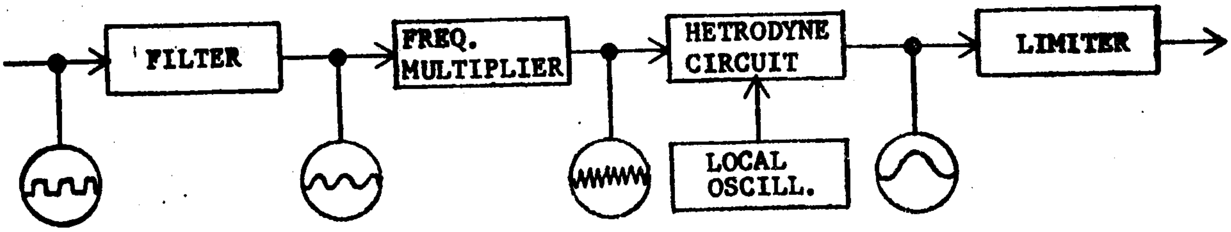


FIGURE 3-4

By using the frequency multiplier and a minimum-drift local oscillator, a sum and difference of the two frequencies is generated in the hetrodyne circuit. Passing through the limiter, the sum frequency is removed which leaves the difference frequency to be transmitted either by direct subcarrier of multiplex for time division transmission. The frequency of the local oscillator and the frequency multiplier are chosen to give the resolution desired for the expected deviation from center frequency.

Of prime interest is the application of signal conditioners to the MOLAB. The four factors that form the basis for acceptance must be:

a) Life

b) Reliability

c) Weight

d) Efficiency

No single conditioner incorporates all of these to an optimum degree, but taking the importance in the order listed, it soon becomes apparent where the trade off must be made.

The life of the unit depends upon the quality of the basic components, the workmanship, and the operational environment. A search of vendor literature illustrates that the mean time between failure is a topic of secondary importance, since the maximum life expectancy listed was "in excess of 2000 hours". The operational temperatures are generally between -55° C and $+100^{\circ}$ C, with a few notable exceptions such as a maximum range of only 0° C to 71° C for one AC amplifier.

Reliability encompasses such parameters as drift-free operation, temperature compensation, packaging, linearity under adverse conditions, etc. The signal conditioners on the market today are geared for this type of performance and, with the possible exception of some very stringent requirements, meet the needs of the MOLAB.

A table of typical signal conditioners (See Figure 3-5) shows that the average weight of a conditioner is about 150 grams. The possible advantage of constructing a signal-conditioning box which would alleviate additional packaging weight has not been applied in actual practice. It is felt, however, that weight reduction could be possible if some flexibility is sacrificed in the construction of such a unit.

The power requirement for an individual conditioner varies according to function and vendor, with an average of approximately one watt. A total value of necessary power could be estimated roughly by using this figure, as the majority of conditioners are of the AC and DC amplifier variety. Pertinent to this is an added feature of some amplifiers that furnishes, as an integral part of the circuit, an excitation voltage to be used with a strain gage. (5-20 volts @ 100 ma)

In summary, the major problem area is to ascertain the overall life expectancy of the signal conditioners under a lunar environment, and to achieve a weight reduction that is within the allowable limits. The reliability, as defined, is not a critical aspect nor is the power consumption if a programmed data collecting and transmission time is employed and followed.

TYPICAL SIGNAL CONDITIONERS

FUNCTION	TYPE	SIZE cm^3	WEIGHT gm	POWER W	TEMP °C	FREQ. RESP.	MFG
DC AMP.	DIFF. CHOPPER	136.8	226	1.4	-55-100	DC - 2 KC	ENDEVCO
DC AMP.	DIFF. CHOPPER PLUS BRIDGE EXCITER	143.5	226	3.2	-55-100	DC - 2 KC	ENDEVCO
DC AMP.	DIFFERENTIAL	82	114	0.7	-20-85	DC - 2 KC	UED
DC AMP.	DIRECT COUPLED	92	142	1.4	-20-85	DC - 2 KC	UED
AC AMP.	CHARGE AMP	40	95	0.56	-20-85	5 - 10 KC	ENDEVCO
AC AMP.	VARIABLE GAIN	49	113	0.70	-40-85	20 - 6 KC	ELECTRO D.
AC AMP.	DC TO DC CONVERT.	127	212	1.82	0 to 71	5 - 4 KC	ELECTRO D.

FIGURE 3-5

4.0 DATA COMPRESSION USING MAGNETIC TAPE AS A STORAGE MEDIUM

A magnetic tape recorder appears to be an acceptable technique for the storage of data under the assumption of a controlled atmosphere. The usefullness of this medium can be extended to provide data compression by simply recording and reproducing the data in different time segments. This is accomplished by recording the data at a reduced tape velocity and reproducing this same information at a higher rate. Effectively, then, this is data compression.

This technique is of particular value when the periodicity of the data is not known. This lack of predictable occurrence makes the use of timed sampling meaningless and, as a result, some method of continuous surveillance is mandatory.

There are certain inherent factors that tend to limit the ratio of recording versus playback time. The present state-of-the-art limit is approximately 50:1 for this type of recorder. These factors are both mechanical and electrical, since the nature of the instrument is a true electro-mechanical device. Some of the obvious mechanical problems are tape storage capacity, mechanical gearing for different Record/Playback speeds, reliable operation under adverse environment, and consistency of tape speed over an extended period of time. A further division of mechanical problems exists between the non-operating state, during the time at which it is subject to high external forces (shock, vibration, and acceleration) during the rocket ascent, and the operating state, when it is subjected to severe environmental conditions (temperature extremes and vacuum).

The requirements for the recorder's safe landing on the moon must be weighed against the following. During transit and soft landing, the external forces will be equal to the conditions encountered in the Saturn V launch vehicle and the soft landing of the LEM. The lunar conditions of vacuum and temperature extremes also will be experienced by the recorder during the operational mode. It is apparent from specifications that some environmental conditioning will be necessary for temperature control; however, the temperature span is greater than the tolerance dictated for some of the scientific instrumentation which it is to record.

During the actual operation of the recorder, the requirement of a constant tape speed is most stringent. A variation will cause a "wow and flutter" component in the data playback. ("Wow" is a periodic variation of less than 10 cps and "flutter" is a variation greater than 10 cps.) This error component is amplified as a function of the record-to-playback ratio.

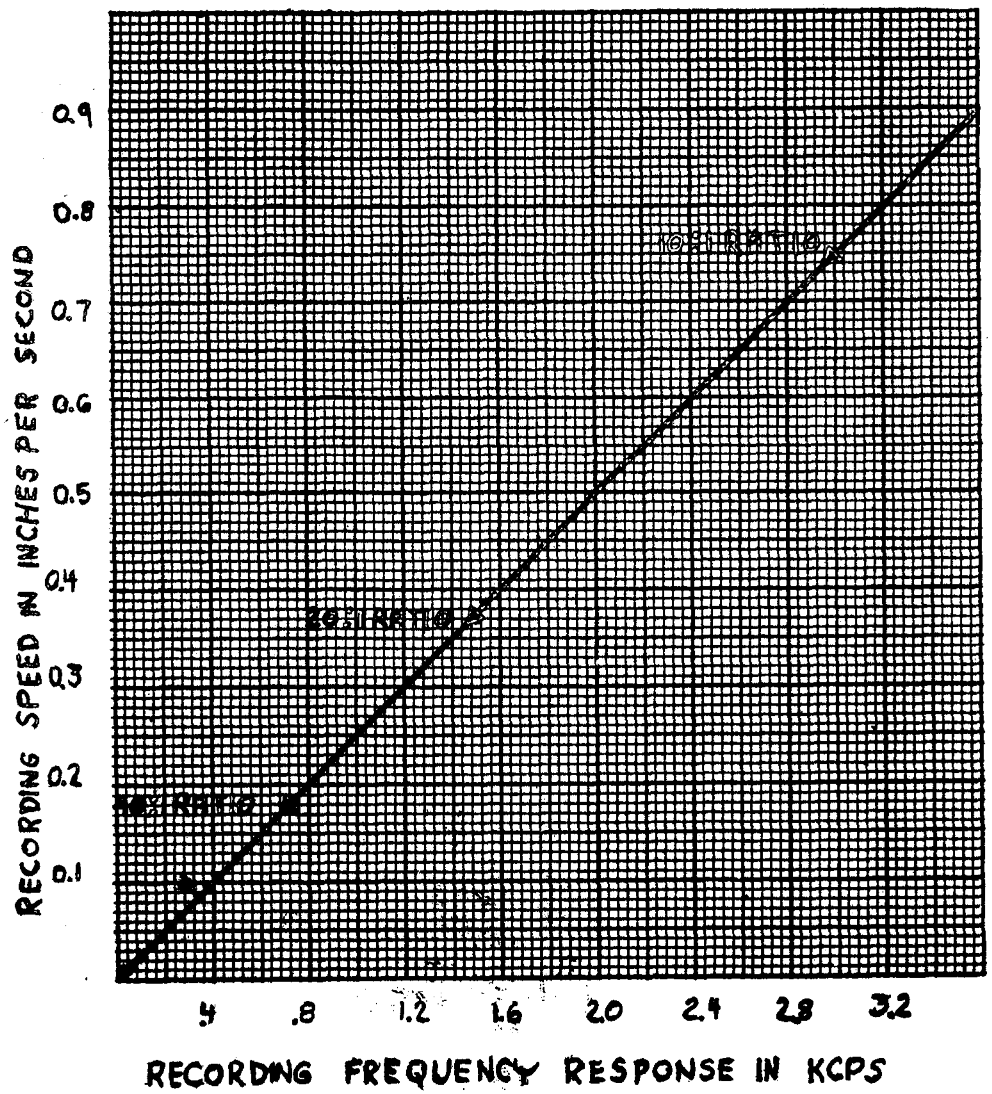
Since the duty cycle of the recorder for the intended mission will be continuious for over six months, the mechanical wear of the moving parts plus the recording heads must be kept to a minimum if a reliable operation is to be achieved.

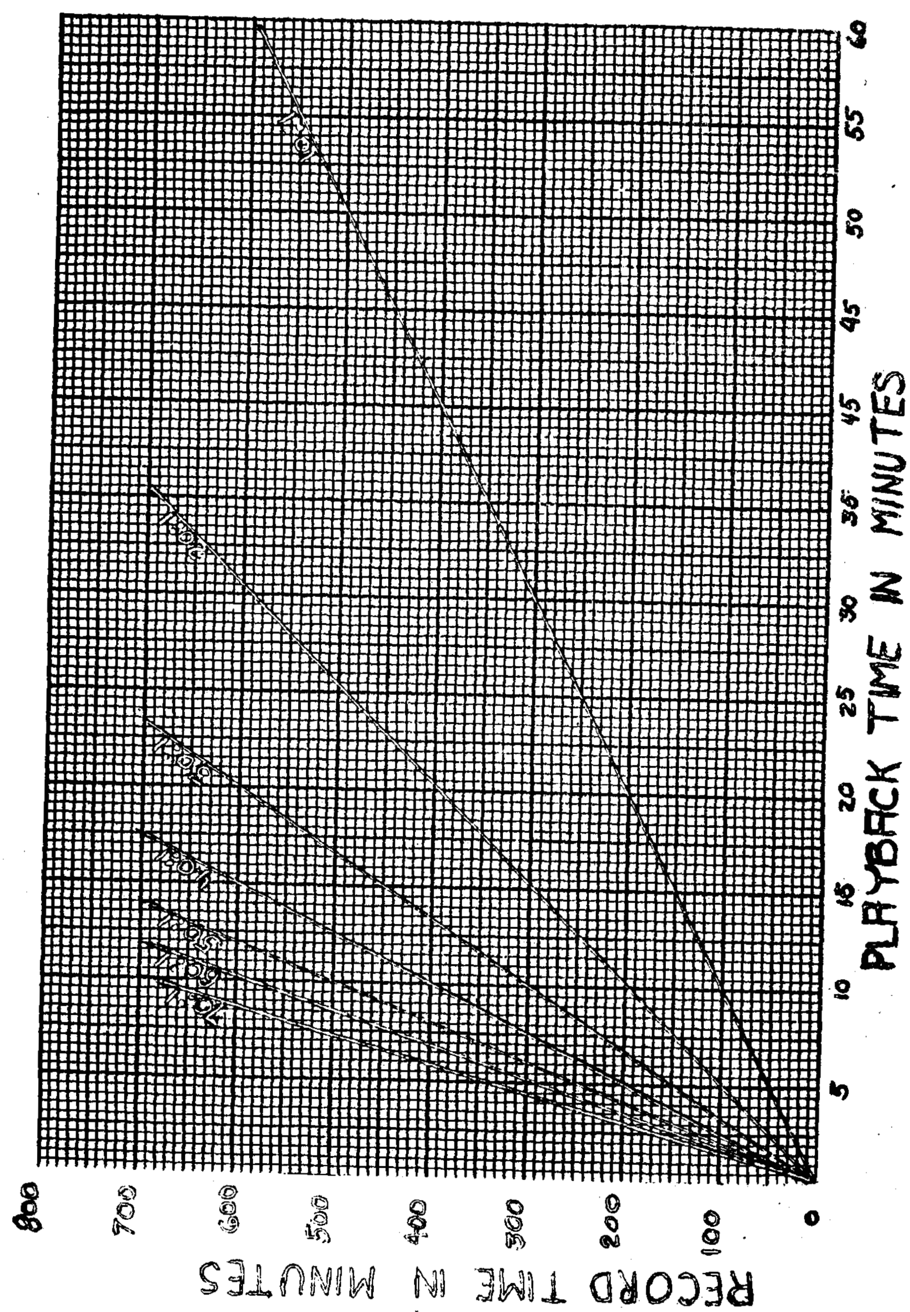
As an example, as the heads wear from the tape friction, a degradation in frequency response is to be expected. Some manufacturers counteract this condition by the immersion of the tape heads in an organic oil, which reduces this friction to a minimum.

The electrical parameters of a tape recorder are largely fixed by mechanical design. As an example, the upper frequency response of a recorder is doubled if the tape speed is doubled. Conversely, the frequency is halved if the speed is halved. Referencing Figure 4-1, an assumed frequency response of 30kc @ 7.5 inches per second was divided by factors ranging from approximately 10:1 to 40:1, with the corresponding frequency response plotted on the abcissa and the recording speed in inches per second plotted on the ordinate. This factor must be taken into account when calculations of ratios are performed. This characteristic does not hold true for the lower frequency response, which usually exceeds a 3 db point below 200 cycles per second.

A more meaningful presentation of the ratios involved is presented in Figure 4-2, which plots the recording time in minutes on the ordinate and the playback time on the abcissa. A series of ratios are plotted for convenience. Assuming the recording time to be 12 hours or 720 minutes, it would require a transmission time to DSIF or MSFN of over 10 minutes at a ratio of 70:1.

BASED ON FREQUENCY RESPONSE OF 30 KC @ 7.5 IPS





VARIOUS RATIOS OF RECORD V.S PLAYBACK TIMES

A more conservative figure of 30:1 would require a transmission time of approximately 24 minutes for the same 12 hour recording time.

One major drawback to using the high ratios, other than the mechanical difficulties, stems from the basic composition of the telemetry signal. As an example of this, on a FM/FM multiplex system, a standard (IRIG) subcarrier frequency is specified with a standard deviation (usually $\pm$ 7.5%) and from this figure the deviation ratio of modulation index is derived.

$$D = \frac{f_d}{B_i}$$

where
f_d = Deviation of RF Carrier
B_i = Information Bandwidth
D = Deviation Ratio

The IRIG standard for FM/FM is a deviation ratio of five (5). The effect of this on the information bandwidth can be seen by:

$$B_i = \frac{f_c \cdot D_p}{D}$$

where
f_c = Sub-Carrier Frequency
D_p = Deviation Percentage
D = Deviation Ratio
B_i = Information Bandwidth

This wide deviation ratio is used to prevent intermodulation distortion in the composite signal, and must be maintained irrespective of the subcarrier frequency. The effect of this ratio on FM/FM data compression is that the information bandwidth becomes a linear function of the compression ratio.

As an example, assume the use of IRIG channel 18, which has an upper subcarrier frequency of 70 kc $\pm$ 7.5%..

$$B_i = \frac{f_c \cdot D_p}{D}$$

where

B_i = Information Bandwidth
f_c = Subcarrier Frequency
D_p = Deviation in Percentage
D = Deviation Ratio

$$B_i = \frac{70{,}000 \cdot 0.075}{5}$$

B_i = 1050 cycles per second

Again assume a record-to-playback ratio of 30:1, using the results obtained in the above equation.

$$B_i' = \frac{B_i}{C_r}$$

where

B_i' = New Information B/W
C_r = Compression Ratio
B_i = Information B/W

$$B_i' = \frac{1050}{30}$$

B_i' = 35 cycles per second

An additional presentation of bandwidth limitation using FM/FM as a data acquisition method is shown in Figure 4-3, in which three representative ratios are given.

The above discussion is primarily related to the problems of recording analog data with emphasis placed on FM/FM using special vco's for operation. By changing the format from analog to digital, an increase in flexibility can be realized. For the

BANDWIDTH LIMITATIONS

(D) DEVIATION RATIO	(C_r) RECORD/PLAY RATIO	IRIG CHANNEL	(f_c) IRIG CENTER F. CPS	(D_p) IRIG DEVIATION %	(B_i) IRIG MAX. FREQ. CPS	(B_i') COMPRESSION MAX. FREQ. CPS	COMPRESSION CENTER F. CPS
5	10:1	11	7,350	7-1/2	110	11	735
		12	10,500	7-1/2	160	16	1050
		13	14,500	7-1/2	220	22	1450
		14	22,000	7-1/2	330	33	2200
		15	30,000	7-1/2	450	45	3000
		16	40,000	7-1/2	600	60	4000
		17	52,500	7-1/2	790	79	5200
		18	70,000	7-1/2	1050	105	7000
5	30:1	11	7,350	7-1/2	110	3.67	245
		12	10,500	7-1/2	160	5.33	350
		13	14,500	7-1/2	220	7.32	483
		14	22,000	7-1/2	330	11.0	733
		15	30,000	7-1/2	450	15.0	1000
		16	40,000	7-1/2	600	20.0	1335
		17	52,500	7-1/2	790	26.4	1750
		18	70,000	7-1/2	1050	35.0	2330
5	70:1	11	7,350	7-1/2	110	1.57	105
		12	10,500	7-1/2	160	2.29	150
		13	14,500	7-1/2	220	3.15	207
		14	22,000	7-1/2	330	4.72	314
		15	30,000	7-1/2	450	6.42	428
		16	40,000	7-1/2	600	8.59	572
		17	52,500	7-1/2	790	11.3	750
		18	70,000	7-1/2	1050	15.1	1000

FIGURE 4-3

purpose of discussion, a model SL-100 tape recorder manufactured by RCA will be used to typify the operation of digital recorders. Specifications for this recorder lists the bit packing density at 1.875 inches per second as 3200 bits per inch. This specification lists an error probability of one bit in 10^5. By relating the packing density of the recorder to a PCM format, the numbers become more meaningful. A typical PCM format may follow a regimen such as:

a) 8 bits per data conversion (data sample)

b) 1 data conversion equals one syllable

c) 3 syllables plus word sync (3 bits) equals one word

d) 64 words equal a minor frame

e) 5 minor frames equal a major frame

This format can be applied, in part, to illustrate PCM application to data compression digital recording, as:

$$\frac{P_D}{B_w} \cdot S_W T_S = C_S$$

where

P_D = Packing Density of Tape
B_W = Bits per Word
T_S = Tape Speed
S_W = Syllable per Word
C_S = Data Conversion per Second

$$\frac{3200}{27} \cdot 3(1.875) = 655$$

Although this 655 conversion is a theoretical maximum, an allowance must be made for sync and error in the system, which would amount to approximately 10% of the total bit rate. The method by which the individual parameters can be varied to accommodate a system is given in a nomograph (Figure 4-4), containing the following functions:

a) Recording speed in inches per second (.3 to 60 ips)

b) Packing density of tape recorders (0.5 to 9 k per inch)

c) Bits per second during recording phase (0.1 to 100 k)

d) Bit conversion (4 bits to 10 bits)

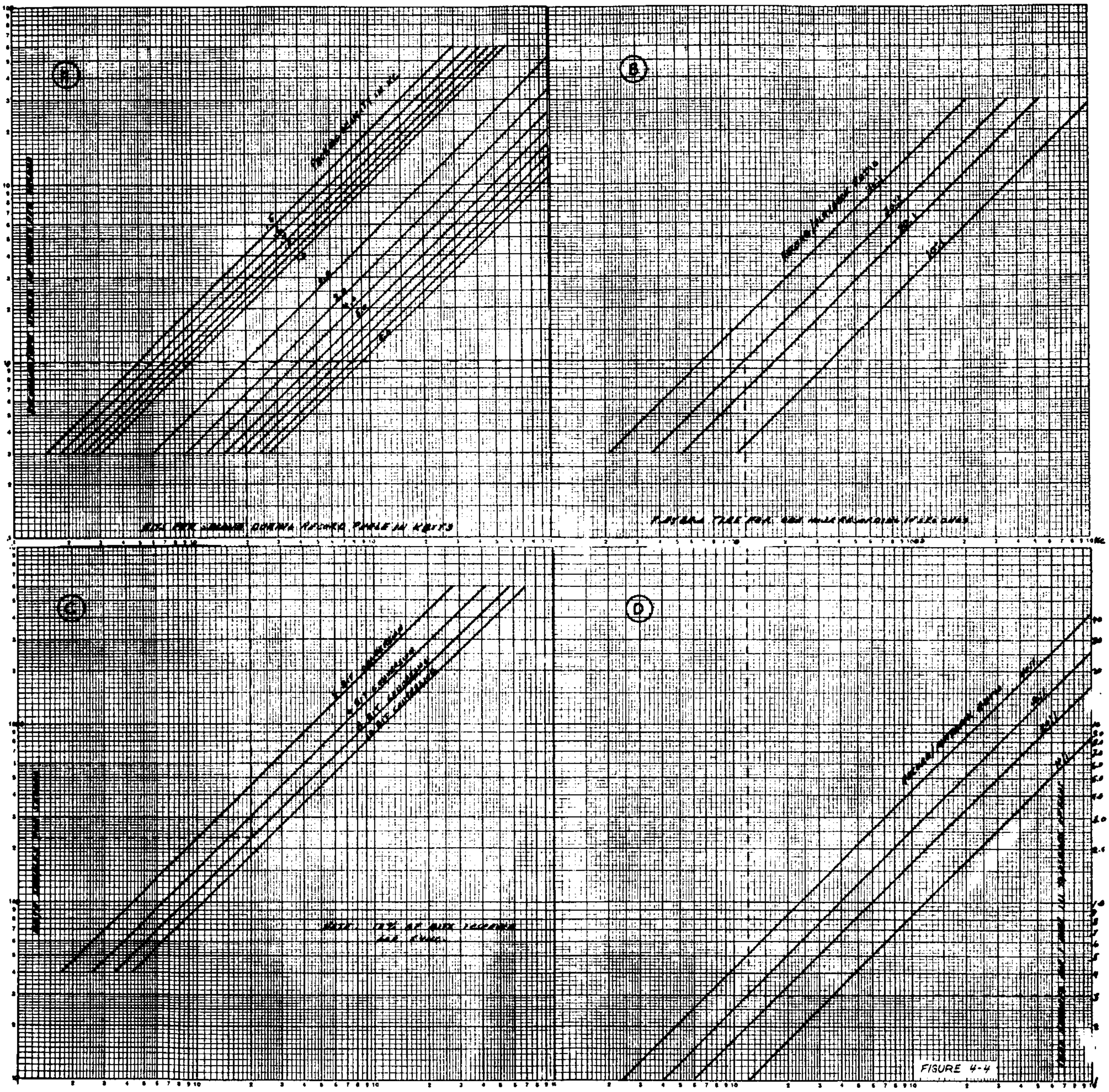
e) Data samples per second (40 to 6000)

f) Record/Playback ratio (10:1 to 40:1)

g) Playback time as a function of one hour recording (20 - 10 k/sec.)

h) Tape requirement for one hour recording (100 ft. to 40 k ft.)

From this nomograph, a point design for a digital data compression tape recorder can be ascertained. The operation of this nomograph is best explained by following an example with the assumed parameters listed below:



a) Recording speed - one inch per second

b) Packing density of tape recorder - 2.0 k bits / inch

c) Accuracy required - eight bit conversion

d) Record / Playback ratio - 30:1

By entering the ordiante of section A at 1.0 inch per second until intersection of the drawn line of 2 k bits occurs, packing density is reached. From this point of intersection, a vertical is dropped to the abscissa, where the bit rate of 2.0 k bits is read. Continuing the vertical line into section C , the eight bit conversion line is intersected. A horizontal projection to the ordinate gives the number of samples per second (approximately 230). Returning to the initial interception on A and continuing the horizontal projection into B to the Record/Playback ratio line of 30:1, and there taking a vertical projection to the abscissa, gives the playback time for a one hour recording. This vertical intercepts at 120 seconds. Continuing the vertical projection into D to the 30:1 Record/Playback ratio line will give the tape requirement in feet (300 ft) when a horizontal projection from the interception is made to the ordiante.

For the MOLAB application of scientific instrumentation recording, the digital type of recorder has the flexibility to accommodate the variety of inputs expected. Approaching the entire package from an integrated design aspect with the instrumentation outputs working directly into an encoder would produce a compact system. The need for special vco's with the exact Record/Reproduce ratio requirements would be eliminated with this type of system. The major drawback to the digital system is the complexity of the encoding system. A more detailed specification sheet for evaluation of the present trends in digital tape recorders is given in Figure 4-5.

An inquiry to various vendors disclosed a form of digital tape recorder that presents a striking advantage for extreme long-term recording. This type is known as an incremental tape recorder, and is unique in the fact that the tape drive is dependent upon the amount of data to be recorded. The data is fed from the source to a buffer, or binary storage device, where it is retained until the buffer has reached a preset capacity. At this time, a signal is generated to dump the stored information onto the tape. The tape transport is driven only to the extent of accommodating the stored data, which has no time limit for accumulation. For non-periodic data, over which a continuous surveillance must be maintained, this particular method has marked advantages: for example, lunar quakes and meteoroid detectors.

DETAILED SPECIFICATIONS ON CURRENT TAPE RECORDERS

Analog - C.H.I. Warwick R.I. (no model no.)

Maximum Tape Capacity	20 ft. K (6100 m)
Frequency Response	100 kc
Record / Reproduce Ratio	Up to 50:1
Wow and Flutter	Less than 0.7% @ 5kc
Power Required	5 watts recorded - 7 watts Reproduce @ 30:1 ratio @ 29 volts
Size	Less than 5700 cm^3
Weight	Less than 3.62 kg
Temperature	-34 to +73°C
	Note: Photos given of external and internal views, Figures 4-6, 4-7, and 4-8.

Digital - RCA Model SL-100

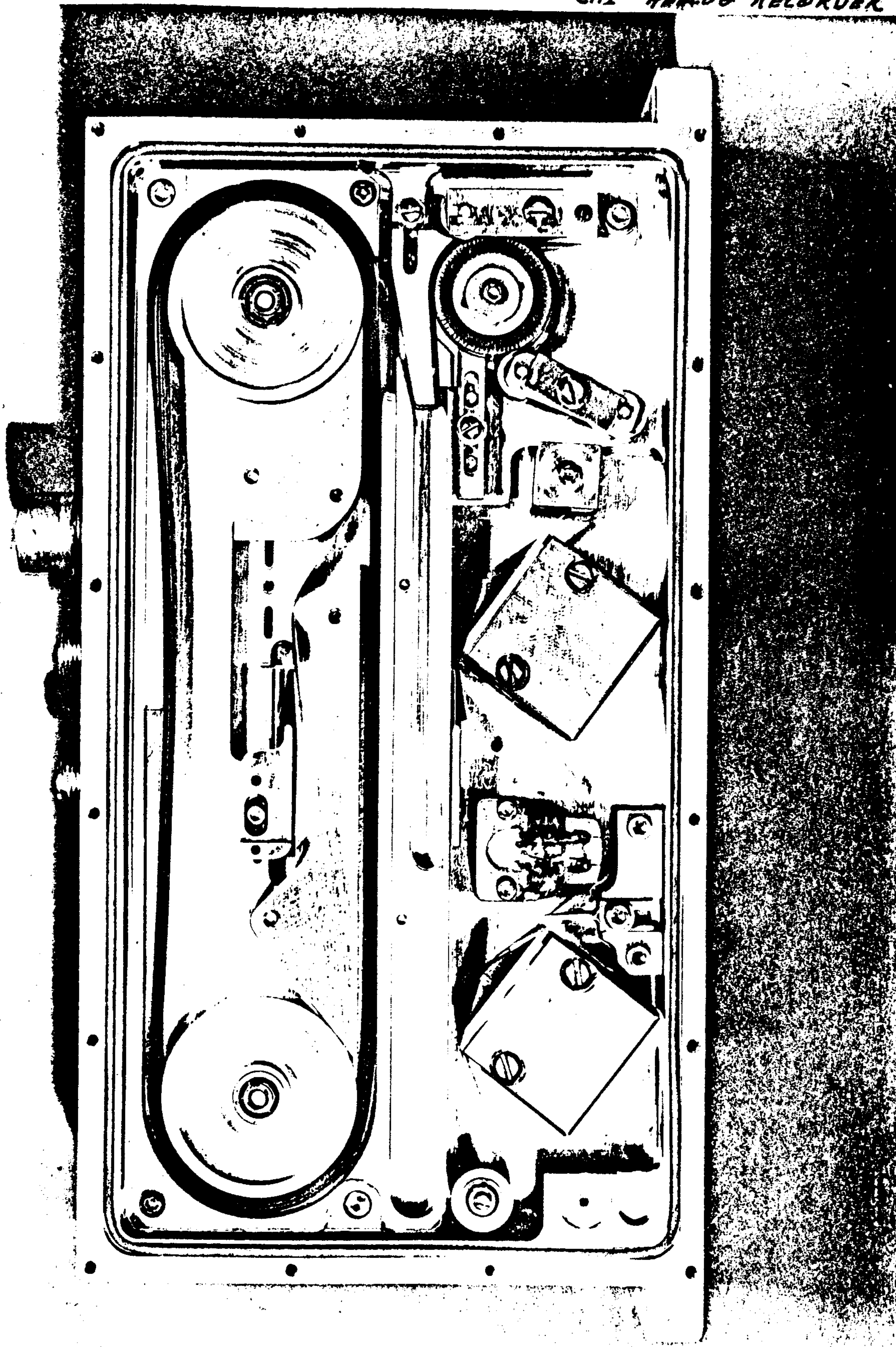
Maximum Tape Capacity	2300 ft.
Packing Density	3200 bits/inch
Record / Reproduce Ratio	Up to 80:1
Bit Rate Stability	Less than 0.1% / sec. / sec. Over 1 k consecutive bits
Power Required	10 watts @ 24 volts
Size	6500 cm^3
Weight	5.45 kg

FIGURE 4-5

In summary, the most direct approach is the analog tape recorder, which has found success in many satellite applications. The prime advantage is found in the simplified electrons required for insertion into the recorder. The limitations are centered in the frequency response with high Record/Playback ratios and in the number of data channels available. The latter drawback can be modified somewhat by using a PAM/FM/FM system or a triple FM system for encoding.

The digital system can more easily trade frequency response for the number of channels and can accommodate a wider variety of inputs than can the analog system. The complexity of the required encoding system can be offset by the greater simplicity of the recording system. It is felt that this particular system offers the better approach to the data compression recording because of the flexibility and freedom from inherent limitations.

CHI ANALOG RECORDER



12/6633

FIGURE 4-6 CHI ANALOG RECORDER

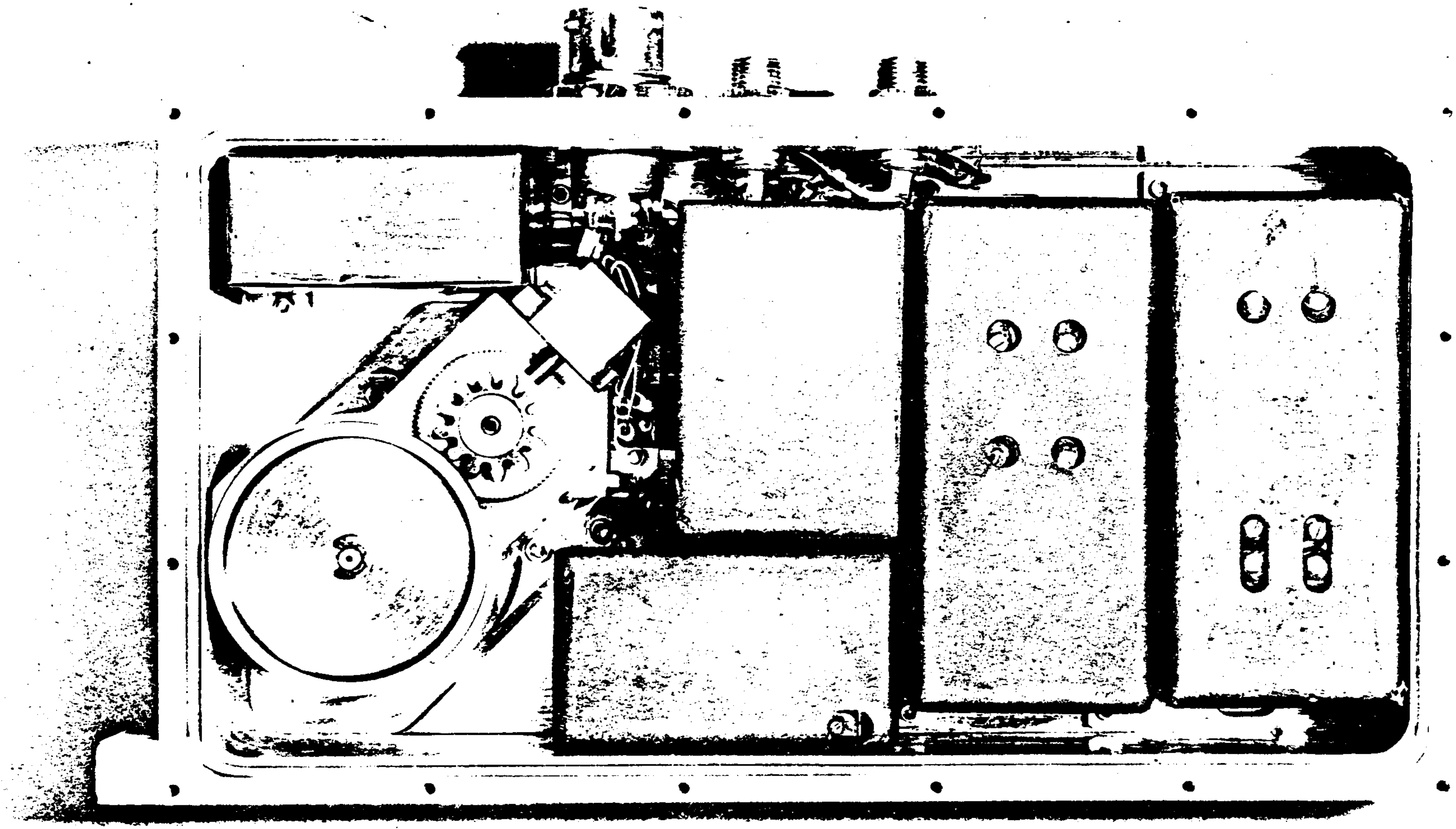


FIGURE 4-7 CHI ANALOG RECORDER

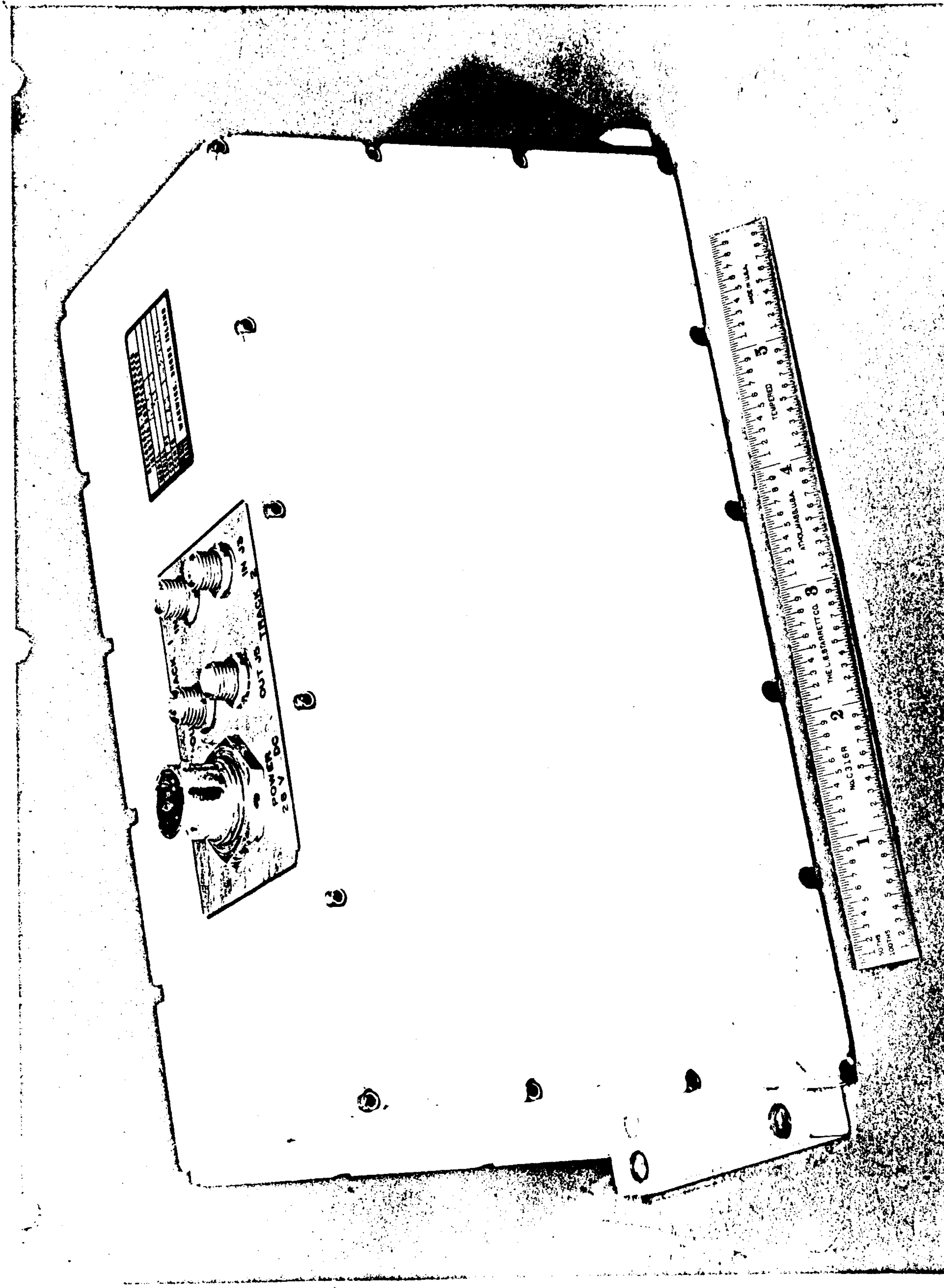


FIGURE 4-8 CHI ANALOG RECORDER

5.0 TELEMETRY SYSTEMS

5.1 INTRODUCTION

This section of the report will describe some of the major types of telemetry systems currently in use or under development that seem to offer the possibility of application on the lunar mission.

The telemetry systems can be roughly divided into three catagories:

a) Frequency Division
   1. FM/FM
   2. SSFM/FM

b) Time Division
   1. PCM/FM
   2. PAM/FM

c) Hybrid Systems
   1. PACM/FM
   2. PAM/FM/FM

Many of these systems have been evaluated by the Inter-Range Instrumentation Group (IRIG) and periodically updated by the Inter-Range Telemetry Working Group (IRTWG) and, as a result, have prescribed standards for their use. Although some deviation is permitted if the conditions so dictate, they have established the working parameters of the missile ranges and the equipment manufacturers. These standards will be referenced throughout this report.

The composite chart, Figure 5-1, shows the advantages and disadvantages of each system to assist in a generalized comparison between each. In addition, a more detailed analysis will describe some of the more salient points of each system.

As noted in the general listing of the telemetry systems, the type of modulation listed for each was FM. This is not to be construed as the recommended modulation technique as AM, PM, and PS also will be investigated for possible use; however, this phase of the system is beyond the scope of this paper.

5.2 FREQUENCY DIVISION SYSTEMS

5.2.1 FM/FM Introduction

This particular system has found very extensive use from Saturn to satellite systems. It is by far the simplest and most reliable method of data transmission in current use.

5.2.1.1 Size and Weight

Telemetry equipment manufacturers have devoted a considerable amount of time to perfecting the sub carrier oscillator by reducing its size and increasing its reliability. The size has been reduced to the point where all 18 IRIG data channels plus a summing amplifier can be packaged in a volume of less than one-fourth the size of a package of cigarettes. The weight of the package would be 32.4 g.

5.2.1.2 Power

The power requirement for each VCO (voltage controlled oscillator) is 84 milliwatts (28 volts d.c. @ 3.0 ma.), which would give a total of 1.6 watts. This is exclusive of any signal conditioning that may be required.

5.2.1.3 Environment

Temperature of useful operation may range from a -55°C to $+125^{\circ}$C with shock and vibration parameters commenserant with normal rocket launching.

5.2.1.4 Frequency Limitations

The maximum information frequency is governed by three factors: the subcarrier center frequency, the maximum deviation, and the deviation ratio. For the 18 IRIG bands, these factors are fixed to a large degree with only the maximum frequency deviation variable (choice of 15% deviation V.S. 7.5%, as shown in Figure 5-2). The information bandwidth (B_i) is calculated as follows:

$$B_i = \frac{F_c D_{max}}{D_R}$$

where B_i = Information Bandwidth

F_c = Center Frequency of Sub Carrier

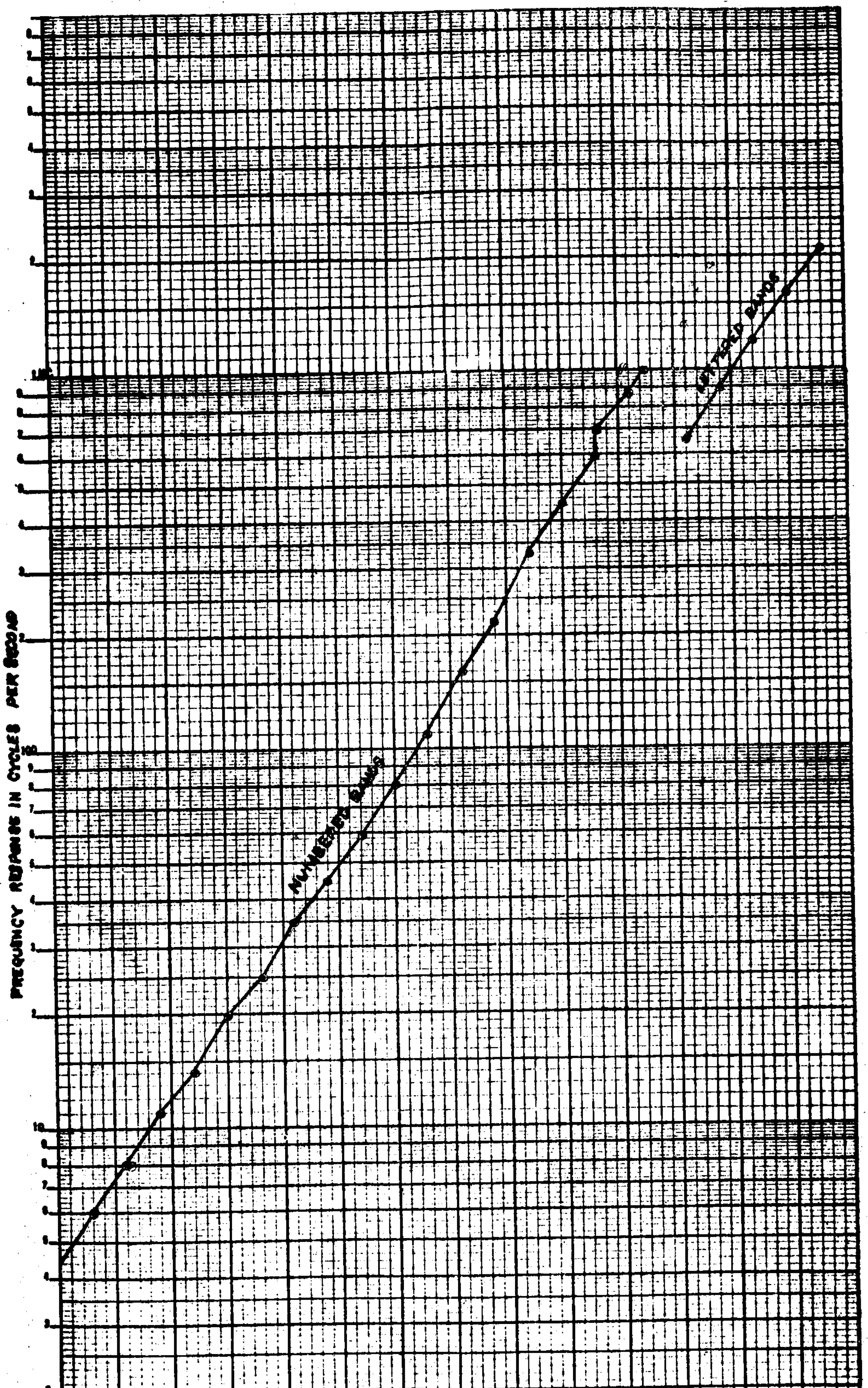
D_{max} = Maximum Deviation of Sub Carrier

D_R = Deviation Ratio

To conform with IRIG standards, a deviation ratio of 5 must be used with a $D_{max.}$ of 7.5% or 15%, total excursion. These limitations give a maximum B_i of 1,050 cps (70 kc $\pm$ 7.5%) or 2,100 cps (70 kc $\pm$ 15%). Further limitations can be noted in the total number of IRIG bands with a response of over 100 cps (8 bands). See Figure 5-2.

5.2.1.5 Channels

The IRIG band allotment gives a total of 18 prime data channels with a deviation of 7.5%. Provision is made for additional higher frequency (B_i) channels using a 15% deviation. However, if these lettered bands are used, it is necessary to omit some bands to prevent adjacent channel interference. See Figure 5-3.



FREQUENCY RESPONSE IN CYCLES PER SECOND
NUMBERED BANDS
LETTERED BANDS
IRIG BANDS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 A B C D E

FIGURE 5-2

CPS RESPONSE	KC CENTER FREQ	IRIG BAND	A	B	C	D	E	F	G	H
		CF in KC	22.0	30.0	40.0	52.5	70.0	95.0	125.0	165.0
160	10.5	12								
220	14.5	13	■							
330	22.0	14	■	■						
450	30.0	15	■	■	■					
600	40.0	16		■	■	■				
790	52.5	17			■	■	■			
1050	70.0	18				■	■	■		
1425	87.5	19					■	■	■	
1875	115.6	20						■	■	■
2475	152.6	21							■	
660	22.0	A		■						
900	30.0	B	■		■					
1200	40.0	C		■		■				
1600	52.5	D			■		■			
2100	70.0	E				■		■		
2850	95.0	F					■		■	
3750	125	G						■		■
4950	165	H							■	

NOTES

1. ■ DENOTES BANDS TO OMIT
2. NUMBER BANDS = ±7.5%
3. LETTER BANDS – ±15%
4. BANDS 20, 21, G, & H TO BE USED ONLY ON 1435-1535 & 2200-2300 MEGACYCLE SYSTEMS.

FIGURE 5-3

5.2.1.6 Bandwidth Calculation

The bandwidth recommended by IRIG is 300 kc, when FM modulation is employed.

5.2.1.7 Accuracy

There are 5 major sources of error in an FM/FM system:

a) Fluctuation error.

b) Carrier sideband distortion in RF and IF circuits.

c) Excess frequency deviation.

d) Sub carrier filter acceptance of adjacent channel side band energy.

e) Sub carrier distortion due to bandpass filter or low pass output filter.

The summation of the above errors is awkward, due to the system-to-system variation. Each vendor of telemetry equipment places a slightly different weight on each particular specification. If a definite vendor was used with a given number of sub carriers and the information given to each sub carrier was of a precisely known value, a more definite accuracy figure could be stated. As imperical tests have been evaluated, the accuracy average for a given system is between 1.6 and 2.4 percent. This figure is based on a minimum of 15 sub carriers operating into a multiplex signal and transmitted at approximately 11 db.

5.2.1.8 Conclusions

Excellent data can be telemetered by this system when the number of measurands is not excessive or where the demand for many high frequency channels is not made. The low power consumption, coupled with the light weight and small size, make this system attractive for some MOLAB applications, such as bio-medical, and some scientific applications.

5.2.2 SSFM/FM

5.2.2.1 Introduction

The single side band frequency modulation technique is applied to the telemetry sub carrier prior to normal RF frequency modulation method and is designed for the transmission of vibration data from large vehicles. Because of transient detection, it is often desired to receive vibration data in a continuous rather than a commutated form. The standard FM/FM channels are limited to the number of data bands available for vibration study; the total being only two which can be used concurrently and have a frequency response of better than 1200 cps (bands of C and E).

The single side band system fits this need for multichannel, high frequency capacity by furnishing up to twenty 30 - 3000 cps bands which may be multiplexed and transmitted simultaneously.

5.2.2.2 Environment

The only data available from the Saturn I-B SSFM/FM System shows that this package is able to withstand the launch parameters associated with this vehicle.

5.2.2.3 Size and Weight

The only data available on the Saturn package gives a weight of 635 g/channel and a size of 900 cm^3/channel in a 15 channel system with a 2 W RF transmitter as an integral part of the package.

5.2.2.4 Frequency Limitation

With this particular system, the frequency limitation occurs at the lower end of the spectrum rather than at the upper end. (See Figure 5-4.) Below approximately 40 cycles per second,

COMPARISON OF SS/FM AND FM/FM

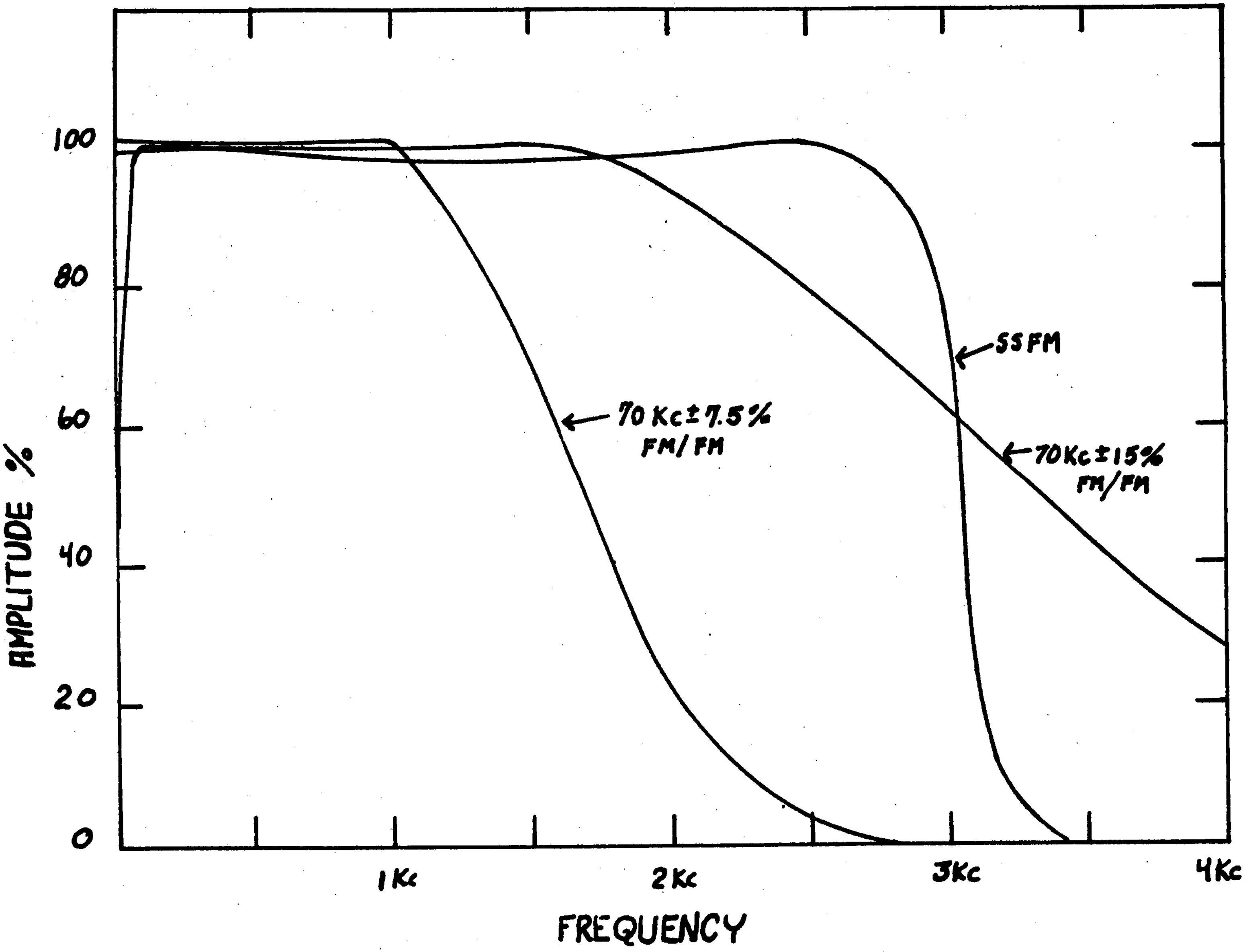


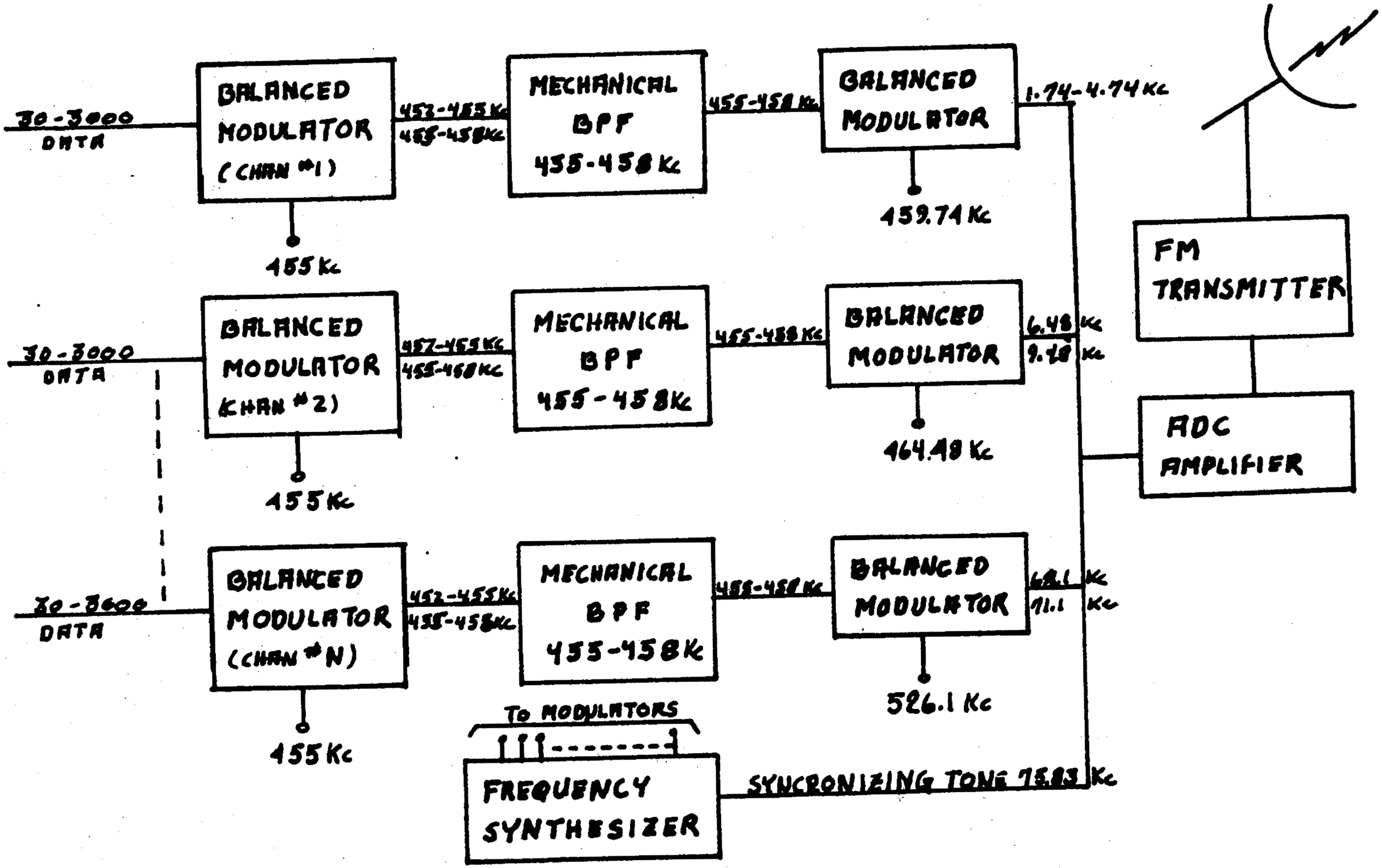
FIGURE 5-4

an extremely sharp roll-off is experienced. With band limiting, an upper frequency is approximately 3000 cps.

5.2.2.5 Operation

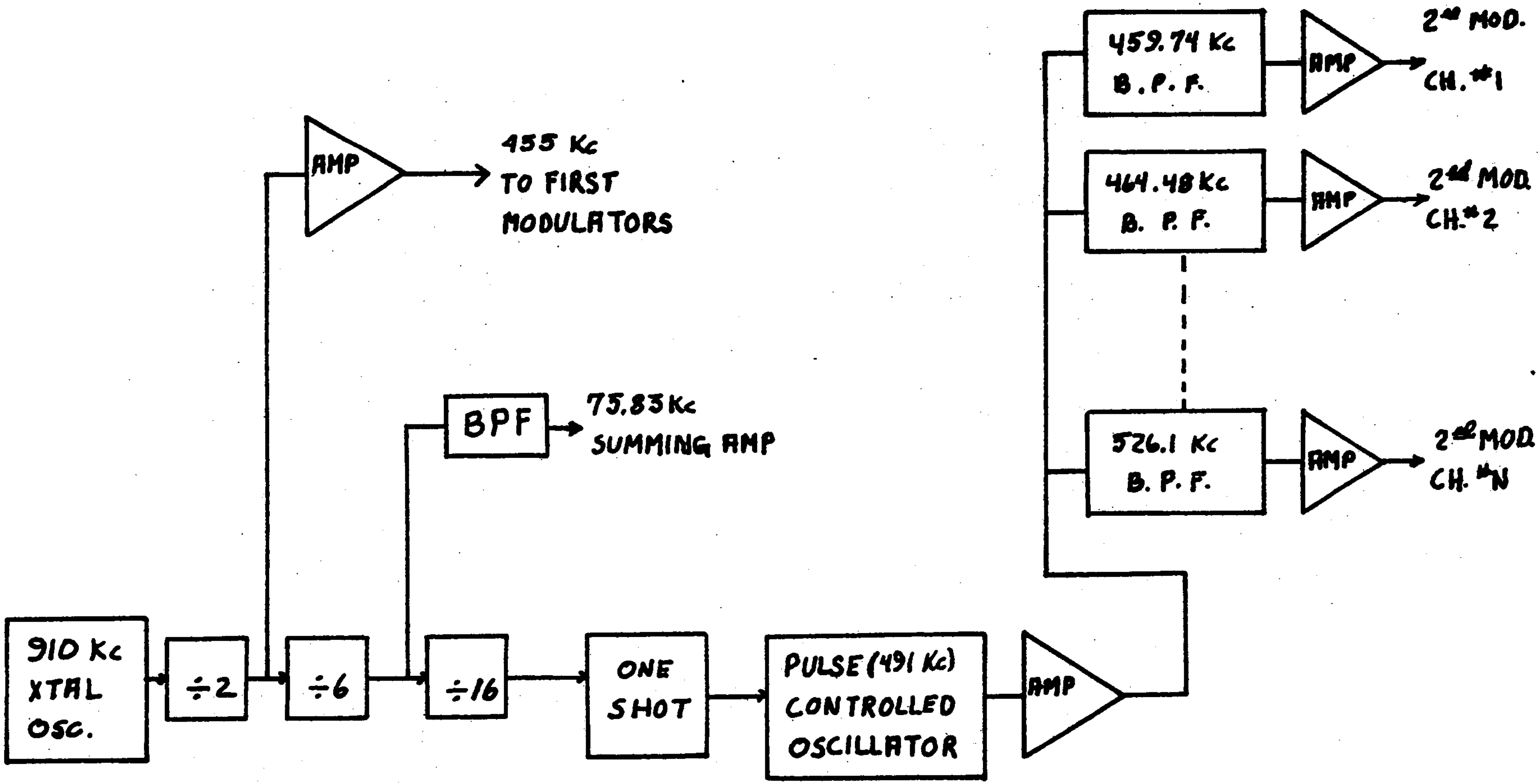
A block diagram (Figure 5-5) shows the basic modules that comprise the system. A signal (30 - 3000 cps) from a vibration transducer enters a balanced modulator where it modulates a stable 455 kc carrier. The output of this modulator is the upper side band with a frequency of 455 - 458 kc, and the lower side band with a frequency ranging between 452 and 455 kc. This lower side is stripped from the composite signal after passing through the BPF, leaving only the upper side band to enter the second balanced modulator. The carrier used in the second modulator is selected to place the lower side band of the modulator output at a predetermined frequency (1.74 kc, 4.74 kc) in the base band. The upper side band is discarded, using filter techniques. This output is then combined with the output of similar channels (each separated about 5 kc) in a summing amplifier and is in turn transmitted.

The carriers required by the modulator stem from a common 910 crystal oscillator. (See Figure 5-6.) The first frequency division gives the 455 kc carrier, which is supplied to and is in common with all first modulators. The second frequency division furnishes a 75.83 kc signal, which is summed with the base band and transmitter for resynthesizing of the carrier at



BLOCK DIAGRAM OF SSFM/FM SYSTEM

FIGURE 5-5



FREQUENCY SYNTHESIZER FOR SSFM/FM

FIGURE 5-6

the ground station. The third frequency division (4.74 kc) is used to trigger a monostable multivibrator which has a period of about eight microseconds. The pulse output from this one chart, in turn, keys an oscillator which has a natural frequency of about 491 kc and a frequency spectrum that contains those frequencies used as carriers in the second modulator. The individual frequencies are selected by band pass filters and distributed.

5.2.2.6 Conclusions

Until all the measurements taken on the MOLAB are defined, it is difficult to anticipate a need for this system. The outstanding feature of this system is, of course, the high frequency response of the data channels. The size and weight per channel in the Saturn configuration make it unattractive in its present form, plus the obvious complexity of the system indicates considerable rework would be necessary before its application to MOLAB measurements could be considered.

5.3 TIME DIVISION

5.3.1 PAM/FM

Pulse Amplitude Modulation was one of the earliest methods of employing a time division principal in the transmission of data. The increased demand for additional data channels beyond the capability of FM/FM led to the development of this simple system.

In principal, it operates as a rotary switch with the individual data signals connected to the contact points and the wiper arm acting as the output signal lead. Usage and standardization by the Inter-Range Instrumentation Group (IRIG) have dictated some basic configurations for PAM; however, with the advent of high speed solid state commutators, the rules are changing to meet a more modern need.

Some inherent design characteristics of commutators become more troublesome when the low level method of commutation is used; among these are switching transients, drift, offset voltage, and back current. The latter two are not self-explanatory and need clarification. The offset voltage is that voltage which is developed between the emitter and collector with the collector-base junction forward biased and the emitter open. Although this voltage is generally kept below one millivolt, it can present a design problem. The back current is that current that flows from the commutator back into the signal source. The results are similar to a bucking battery.

5.3.1.1 <u>Size and Weight</u>

As the MOLAB mission requires a very extended operating life, the probability of using a motor driven commutator is slim; therefore, all subsequent values in this section are based on the solid state commutator.

The packaging of the commutator (or multiplexer) is available either with or without the programmer incorporated as an integral part of the commutator. The programmer, which contains all the switching within the commutator and produces any clocking pulses that are required, plus producing the correct format for synchronization, may be housed as a separate unit. In large systems that require the service of several commutators, it is advisable to use this method for control. With this regimen, the individual weight/channel is near 1.5 grams and the weight required for control decreases (percentage-wise) with the number of channels used.

For the smaller system of, say 45 channels, an integrated system could be used which would give an overall weight/channel of about 17 grams.

Similar orders of magnitude are evident in rating the size/channel with the independent channel being approximately 2.0 cm^3 and the integrated system volume just in excess of 12 cm^3.

The size and weight of the independent programmer is so closely tied to the system that it controls, that a definive scale cannot be applied.

5.3.1.2 Power

Most of the commercial units (solid state commutators) require an input voltage of from 24 to 28 volts d.c. for operation. An average commutator with an integrated programmer draws about 90 mw/channel for a 45 channel system. This power becomes less as the number of channels increases and particularly so if multiple commutators are controlled from a common programmer.

5.3.1.3 Commutation Rate

The standard IRIG commutation rate is 900 pps, and is composed of two functions: 1) the total number of data inputs which equals one frame and 2) the total number of frames per second. These two identities are interchanged to suit a particular condition, but usage has resolved these variables into three popular combinations:

Number of samples/frame	Frames/ second
30	30
45	20
90	10

The number given for samples/frame (data inputs) must, in each case, be reduced by two which are reserved for synchronization.

Again, the need for an increase in the data handling capacity of the system has forced the state-of-the-art to higher commutation rates. This high speed commutation can, in general, only be realized by using the solid state commutators which operate at rates up to and above 30,000 pps. The limiting factor that governs the upper rate of these units are the switching rate of the commutator and the logic gates within the programmer.

This high speed commutation provides more data channels in a given segment of time plus an increase in the frequency response of selected data channels.

5.3.1.4 Input Levels

Two basic types of commutators are in current use: the high level commutator that accepts signal voltages ranging from zero to five volts d.c. and the low level commutator that accepts signal voltages ranging from zero to ten millivolts d.c. Each type offers advantages for a particular system and is described below.

a) High Level Commutators

Because of the high operating voltage at which this commutator operates, it has the advantage of being free from the effects of offset voltage and back current plus the fact that any switching transients that are developed are not in turn amplified by a subsequent driver, which can result in inaccurate and confusing data. A comparison study between two 45 channel commutators with integrated programmers indicates an advantage for the high level commutator with respect to physical parameters.

	Weight/channel in grams	Size/channel in cm^3	Power/channel in milliwatts
High Level	17.6	12.3	89
Low Level	45.3	34.4	133

The above figures were obtained from one vendor's literature with the release date in the third quarter of 1963.

Although these figures favor the high level commutator, they must be weighed with the number and type of measurements to be taken. Subsequent discussion will illustrate the effect that the measurand type has on determining an optimum design.

b) Low Level Commutators

The ability of low level commutation to save weight, space, and power is exemplified in the following table, which depicts two systems operating on the 150 temperature measurements proposed for the MOLAB.

<u>System One</u> High level commutation plus d.c. amplifiers.

	Weight/channel in grams	Total (Kg)	Size/channel in cm^3	Total (cm^3)	Power/channel in milliwatts	Total (W)
DC Amplifier	114	17.1	82	12.3K	700	105
Commutator	17.6	2.64	12.3	1.845K	89	13.3
Total	131.6	19.74	94.3	14.145K	789	118.3

<u>System Two</u> Low level commutation

	Weight/channel in grams	Total (Kg)	Size/channel in cm^3	Total (cm^3)	Power/channel in milliwatts	Total (W)
Commutator	45.3	6.75	34.4	5160	133	20

<u>Comparison</u>

	Weight	Size	Power
High Level	19.74 kg	14,145 cm^3	118.3 w
Low Level	6.75 kg	5,160 cm^3	20.0 w
Difference	12.99 kg	8,985 cm^3	98.3 w

Admittedly, this is a "worse case" condition and, with integrated design of the amplifiers, the difference between these two systems would be lessened to a considerable degree. However, it does emphasize an area of possible reduction in weight, size, and power.

In summary, the savings that the low level commutator offers in size, weight, and power consumption are commendable for the MOLAB mission when many of the signals to be transmitted are of the low level nature. If the problems associated with the low level method of commutation can be resolved, it becomes very competitive with the reliable and accurate high level system.

5.3.1.5 Super and Sub Commutation

The PAM system is very flexible as it is simple to trade data channels for frequency response. Subcommutation allows many measurements of relatively low frequency to be programmed into a common carrier. Figure 5-11 shows how subcommutation, as supplied to a PAM/FM/FM, would operate.

Conversely, super commutation, which also is referred to as "cross strapping", is performed by feeding the data signals to more than a single contact per frame. Supercommutated signals are cross strapped at discrete intervals to provide a balance in sampling.

5.3.1.6 Synchronization

The synchronization of PAM signals is accomplished in two steps. First the basic pulse repetition rate of the data signal is sensed by using a phase locked loop circuit which is coupled with a voltage controlled oscillator to establish an identical frequency in both the transmitter and the receiver. Once this PRF has been established, frame synchronization is achieved by detecting a unique pulse in the data train which was encoded by the commutator. This unique pulse may have either amplitude or duration as the distinctive characteristic.

All of the above synchronization is obtained by using digital techniques, and the process of self checking is continuous.

5.3.1.7 Summary

PAM offers the flexibility and capacity needed for a large system if the accuracy requirements do not become too severe. An accepted trade off point between PAM and PCM has been found to be about 2 percent accuracy, but this figure needs substantiation based on the particular system that is to be instrumented.

5.3.2 PCM/FM

The need for greater accuracy than is obtainable with PAM, yet retaining the flexibility and channel capacity of that system, led to the implementation of PCM. It is a system that makes the maximum use of digital logic in multiplexing and encoding. The encoding is performed by creating a PAM pulse train and then converting these amplitudes into a binary equivalent before modulation. In recent years, this system has been used on such programs as Titan, Polaris, and Gemini and is applicable wherever an accuracy as great as a tenth of a percent is desired.

5.3.2.1 Volume and Mass

In a completely integrated system containing multiplexers, amplifiers, programmers, etc., an average mass/channel is about 133 grams with the volume/channel of about 155 cm^3. Where functional chips are used, the volume and mass are reduced, but the addition of a programmer must be included as a necessary addition.

5.3.2.2 Power

The power requirement for the integrated system is about 600 MW per channel but a considerable savings in power can be realized by using functional chips.

5.3.2.3 Encoding and Format

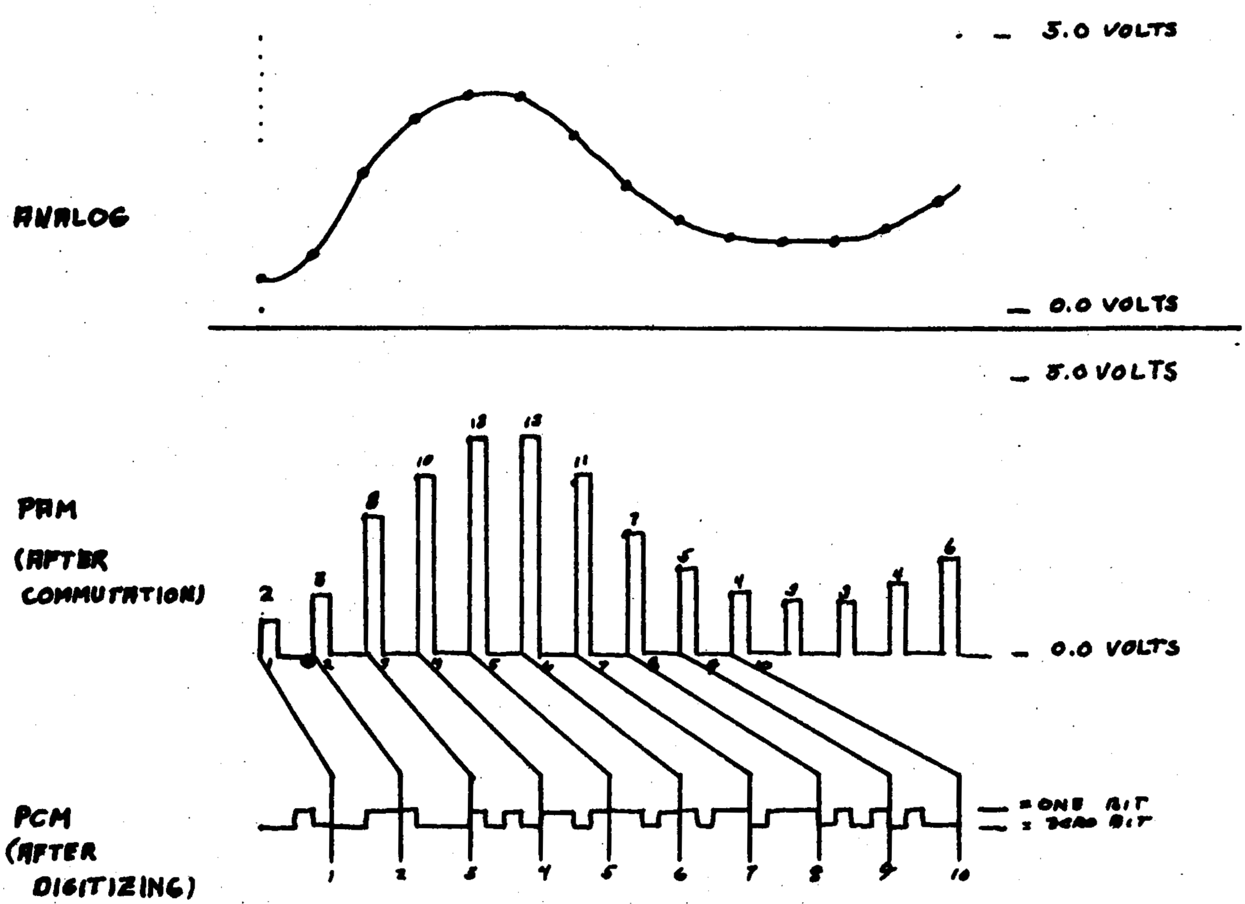
The PCM encoder is usually furnished as an all inclusive package which accepts raw data from the transducers --- both high and low level --- and performs multiplexing, amplification, digital conversion, formating and filtering. Referring to Figure 5-7, a step analysis can be performed. In this sketch a single analog signal is sampled as shown with its equivalent PAM pulse train. This PAM pulse train is fed to a 'sample and hold' circuit or capacity switch which is charged to the level of the PAM pulse. The output gate of the sample and hold circuit is then connected to a high impedance buffer amplifier and then to an A/D conversion circuit such as a successive approximation type. The output of the A/D converter is fed to a format generator, where it is correctly timed sequenced into words and frames. This pulse train is then processed by a NRZ generator and harmonic filter prior to its insertion into the transmitter.

Most encoders provide for the inclusion of externally generated digital data into the format after the A/D converter circuitry. Also, provisions are made for formating bi-level data into the pulse train.

5.3.2.4 Accuracy

The ability of the PCM system to resolve a PAM pulse is a function of the number of bits per conversion. Three lenths are in common usage which seem to serve the majority of needs:

CONVERSION FROM ANALOG TO SAMPLED ANALOG TO DIGITAL FORM



DIGITAL READOUT BASED ON 4 BIT CONVERSION NRZ

FIGURE 5-7

Bits/Conversion	Resolving Power	MV/Bit @ 5V F.S.	Accuracy %
6	1/63	79	1.6
8	1/256	19	0.4
10	1/1024	4	0.1

The word "accuracy" as used here only means the accuracy of conversion and does not imply an overall accuracy of the system..

The overall accuracy of the system is effected by the transmission S/N ratio which is expressed as the probability of one bit error in N number of bits. IRIG standardization has published the following:

S/N Ratio (in. db)	1 Bit Error In.
13	10^5
15	10^6
17	10^7

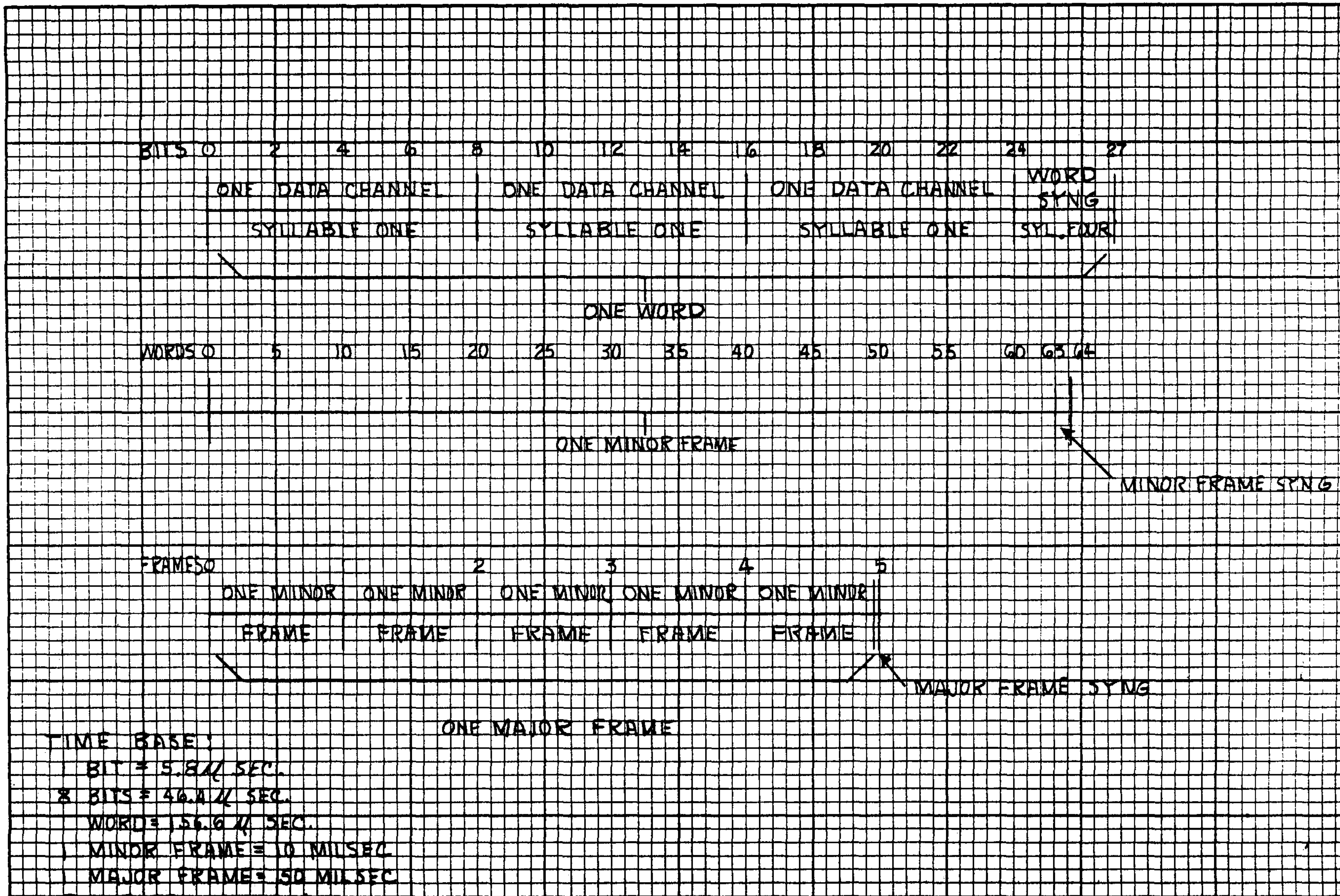
5.3.2.5 <u>Programmer</u>

A stable crystal oscillator forms the basic clock pulses from which all other pulses are derived. Clock pulses are used to drive the multiplexer(s), encoder, NRZ generator, timing sequence of super and subcommutation, and timing sequence of external digital information. The frequency selected as the prime clock rate is dependent upon the desired bits per word, the number of prime channels, and the accuracy desired.

5.3.2.6 Format

The exact format, through necessity, must be defined for an optimum system; however, "off the shelf" encoders are available with 200+ data channel capability. A typical unit in this class is the Epsco PC5 which is used in the Gemini project at the present time and serves as a current state-of-the-art example. The format is diagrammed in Figure 5-8 and consists of three 8 bit syllables to form one word. Each syllable constitutes a single data channel and each word includes a 3 bit sync pulse. Sixty-four words make up a minor frame with the sixty-fourth word (27 bits) reserved for synchronization (Barker word derivation). Five minor frames comprise one major frame with the last 27 bits reserved for major frame synchronization. The output is, of course, non-return to zero (NRZ).

This format allows a flexability for super and subcommutation plus the insertion of bi-level measurements (48).



TYPICAL PCM FORMAT

FIGURE 5-8

5.3.2.7 Synchronization

Synchronization is obtained by first establishing the basic pulse repetition rate via phase lock loop circuit coupled with a voltage controlled oscillator. By using digital logic, the minor frame code is detected, then the major frame. For added verification, word sync is defined during the initial acquisition, then is eliminated as major and minor frame codes define synchronization on a continuous basis.

5.3.2.8 Serial/Parallel Transmission

An early limiting factor in data processing was the upper frequency response of instrumentation tape recorders which necessitated the transformation of serial data into parallel form prior to transmission, which enabled the PCM to be recorded on 16 tracks in parallel. With the introduction of instrumentation recorders with frequency response extending to greater than one megacycle, this serial-to-parallel transition was not needed and recordings are made using a single track.

As a point of interest, this extended range also introduced the process known as predetection recording which allows the recording of the telemetry signal prior to demodulation in the receiver. An advantage is the ability to optimize the signal processing by band limiting and filtering before detection by the receiver. One limiting condition is the cost and complexity of the recorder and the high tape speed which is necessary for recording.

5.3.2.9 Computer Formating

Since the amount of data generated with multichannel systems is voluminous. it is desirable to reduce this information with the aid of a computer. PCM is readily adaptable since it is received in binary form and with minor formating can be made compatible with most digital computers.

5.3.2.10 Summary

The accuracy, versatility, and ability to retain this high accuracy in the presence of noise make this system a major contender for the MOLAB mission.

5.4 HYBRID SYSTEMS

5.4.1 PACM/FM

This hybrid system is a blend of PCM and PAM and was first proposed by Aeronutronics, a Division of the Ford Motor Company, as a "standard military telemetry system". At the present time there is little hardware available with most vendors of airborn telemetry equipment doing preliminary designs and breadboard mockups.

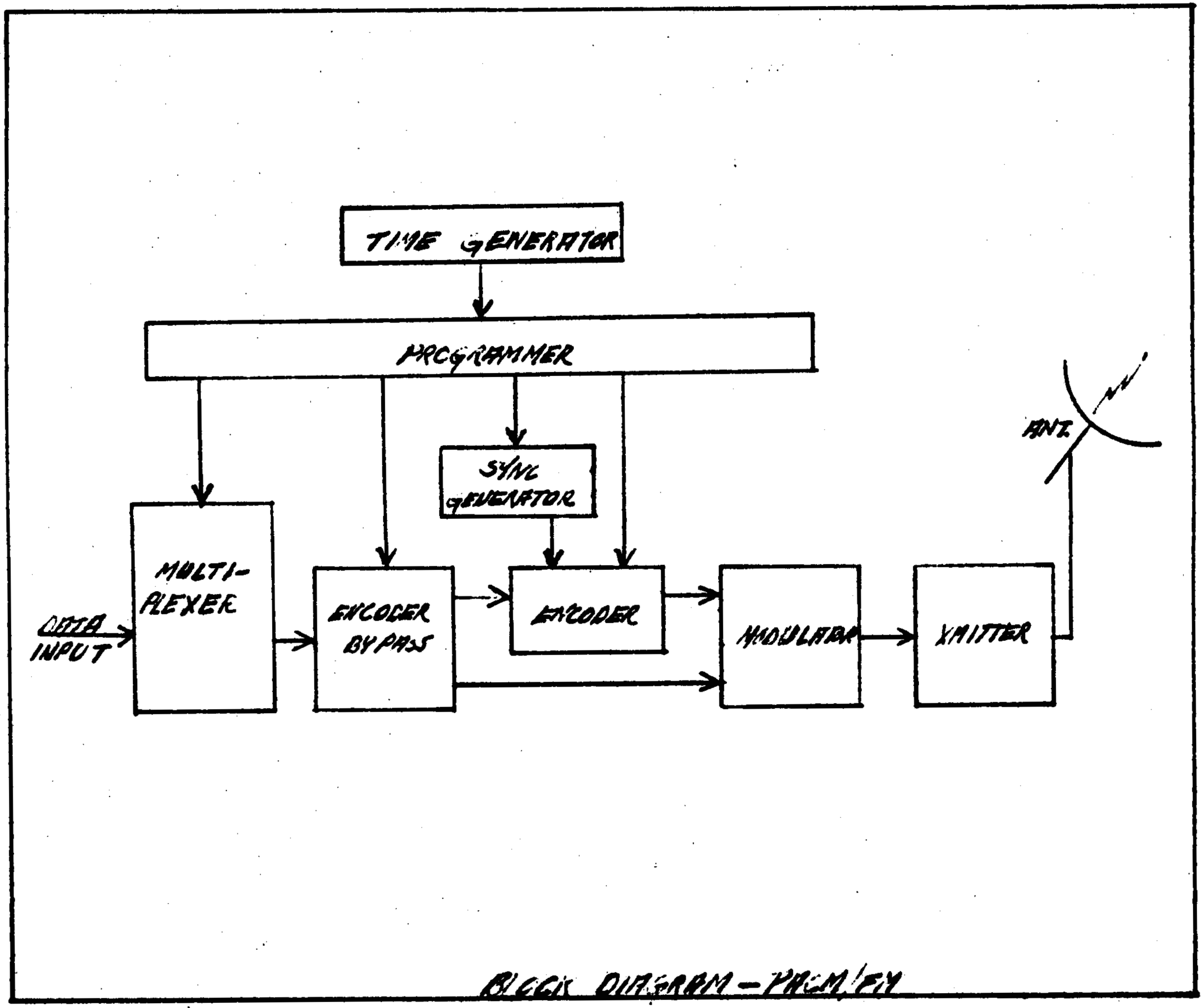
In theory, the hybrid systems combine the virtues of both systems so that each measurement may be correctly processed and routed to that portion of the system that will encode most effectively. The word theory is used since there is no major user of this equipment at the present time.

5.4.1.1 Size, Weight, and Power

Off-the shelf packages are not available,which forces conjector as to the physical properties. From general conclusions made by the Ford Motor Company it is estimated that these properties would be slightly higher due to the greater complexity of the system in general and the programmer in particular.

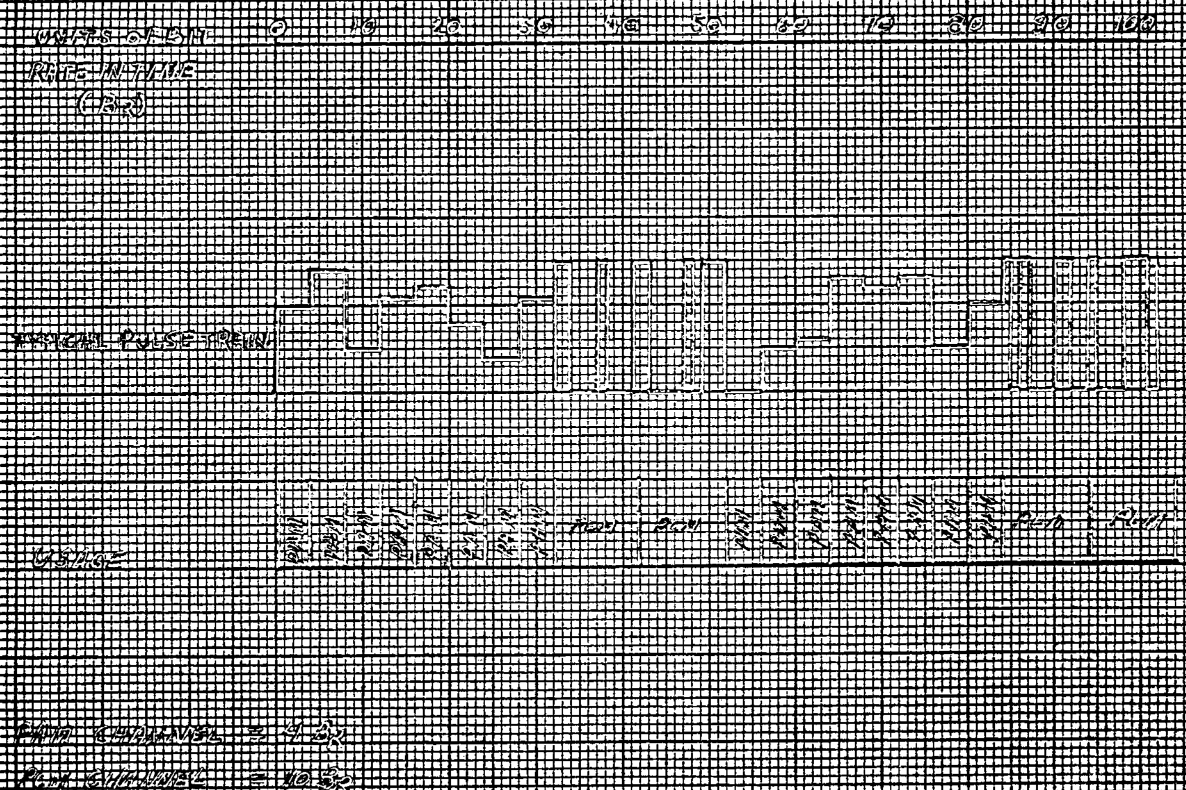
5.4.1.2 System Operation

The PACM system retains all of the features of both PAM and PCM plus an additional devise called an encoder bypass. See Figure 5-9. The programmer performs the function for both systems and controls all multiplexing, encoding sync insertion, etc. The time base generator operates at the PCM bit rate with the PAM pulse being some fixed integral multiple of that bit rate. See Figure 5-10. In the time slot reserved for PAM transmission, the encoder bypass couples the multiplexer output to the modulator and disables the PCM encoder. Conversly, this gate is



BLOCK DIAGRAM – PACM/FM

FIGURE 5-9



EXAMPLE OF PACM PULSE TRAIN

FIGURE 5-10

closed when PCM encoding is in process. The two systems interweave in the same data pulse train and the end controlling device is the encoder bypass.

5.4.1.3 Pulse Format

The recommended bits per word is between 4 and 14 NRZ for PCM; the PAM portion requires a 100% duty cycle amplitude modulated output for operation. There is no defined ratio between the amount of PAM or PCM that is to be carried in any one system. The flexibility is good.

5.4.1.4 Synchronization

Frame synchronization is obtained by the insertion of a 21 bit Barker code in the pulse train. Ground station techniques are similar to PCM except that no word sync is used.

5.4.1.5 Summary

PACM offers the variety and flexibility found in no other system. In a single data train the extreme accuracy of PCM and the data handling capacity of PAM are combined with the ratio commensurable with the application. The bandwidth limitation is set by the basic bit rate of PCM; therefore, little change is necessary in this aspect.

The disadvantages of this system are more intrinsic as the system is complex. The reliability for such a mission as MOLAB is unknown. The system is here and warrants further consideration.

5.4.2 PAM/FM/FM

This hybrid system combines time division (PAM) and frequency division (FM) into an integrated complex that is extremely versatile. Many vehicles require two types of information: 1) the type that needs continuous surveillance, hence FM, and 2) those functions which need only be sampled periodically in order to extract useful information. If many restrictions are placed on the physical characteristics of the telemetry system, then PAM/FM/FM often presents a unique solution.

5.4.2.1 Size and Weight

By using a micro-miniature voltage controlled oscillator for FM and a commutator with an integrated programmer for PAM, a compact unit weighing about 15 grams/channel can be realized.

The package noted above would have a volume of about 10 cm^3/channel. It should be noted that the "package" need not be physically in the same container as the commutator (unit programmer) and the vco's can be remotely located if the logistics warrant.

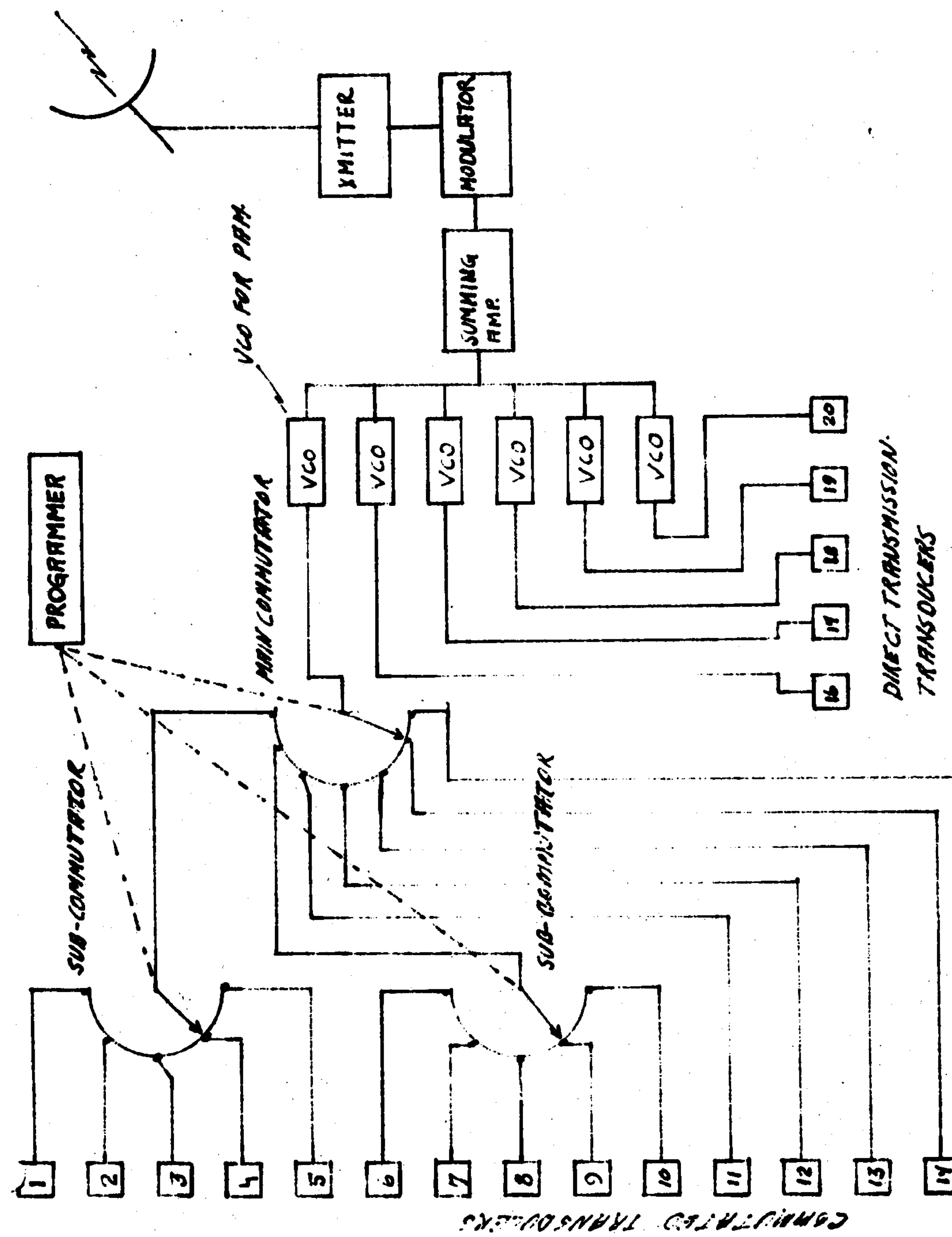
5.4.2.2 Power

With reference to the above package, a power figure of 180 mW/channel is normal, based on the use of 45 PAM channels and one vco for drive.

5.4.2.3 Operating Characteristics

The PAM commutator accepts inputs from the end instruments or signal conditions and produces a standard PAM output signal complete with synchronization pulses. Instead of modulating a transmitter directly, the pulse train modulates a standard vco. The frequency modulated output from the vco is fed to a summing amplifier where it is combined with outputs of other vco packages. These additional vco's may be directly coupled as shown in Figure 5-11, or may contain additional PAM signals originating from independent commutators.

The commutation rate (pps) for PAM/FM/FM is dependent upon the vco used to modulate its signal. A commutation rate as low as 90 pps, which would require a minimum vco frequency of 14.5kc ± 7.5% to 900 pps, would require the use of 70 kc ± 15% vco for proper operation.



BLOCK DIAGRAM OF PAM/FM/FM USING SUB-COMMUTATION

Figure 5-4

5.4.2.4 Summary

For direct readout of scientific packages, this system has been proven in many applications. Its compact size and weight may offer a considerable advantage when instrumentation of the scientific experiments on the MOLAB are made.

SYSTEM	WEIGHT/ CHANNEL	SIZE/ CHANNEL	POWER/ CHANNEL	PRIME DATA CHAN.	NORMAL ACCURACY	COMMUTATED OR CONTINUOUS	RELIABILITY	FLEXIBILITY	HI FREQ. CHANNELS	SIGNAL TO NOISE R. REQ.
FM/FM	2.5 GR. INDIV. 2.9 GR. WITH 18 CH. MOUNT.	1.2 CM^3 21.6 CM^3 18 CHANNELS	84 MW.	NORMAL 18 @ 7.5% DEV. LESS IF 15% USED	APPROX 2%	CONTINUOUS	EXCELLENT	FAIR	LIMITED TO VERY FEW	9-12 DB
SSFM/FM	535 G. WHEN COMBINED WITH 2 W. XMITTER	APPROX 900 CM^3 WHEN COMBINED WITH 2 W. XMITTER	—	10-20	APPROX 5%	CONTINUOUS	FLOW IN SATURN-NOT WIDLY USED	FAIR	EXCELLENT (MAIN USE)	9-12 DB
PCM/FM	USING FUNC-TIONAL CHIPS APPROX 2.0g PER CHANNEL	.6 CM^3 USING FUNCTIONAL CHIP CONTAIN-ING 8 CHANNEL	208 MW WITH FUNCTIONAL CHIPS	GENERALLY HIGH	FUNCTION AT BITS/SYLLABLE & SIGNAL/NOISE RATIO	COMMUTATED	GOOD-SOME FLIGHT TEST IN BOOSTERS & SATELLITES	GOOD	GOOD (SUPER COMM)	15 DB - 10^6 17 DB - 10^7 BIT ERROR
PAM/FM	17.6/CHAN WITH PROGRAM 1.5 G/CHAN USING FUNCTION CHIPS NO PROGRAMMER	12.3 CM^3 WITH PROGRAMMER APPROX 2.0 CM^3 WITHOUT PROGRAMMER	89 MW WITH PROGRAMMER	IRIG STD 30 OR 45	APPROX 2%	COMMUTATED	VERY GOOD	VERY GOOD	GOOD (SUPER COMM)	9-12 DB
PACM/FM	NO PUBLISHED DATA	NO PUBLISHED DATA	NO PUBLISHED DATA	GENERALLY HIGH	LIMITING FACTOR PAM - PCM FUNCTION AT BITS/ SYLLABLE & S/N	COMMUTATED	UNTESTED IN MAJOR FLIGHT VEHICLE	EXCELLENT	GOOD (SUPER COMM	15 DB - 10^6 17 DB - 10^7 BIT ERROR
PAM/FM/FM	20-25G	APPROX 14 CM^3	APPROX. 180MW.	IRIG STD 30-45	APPROX 2%	COMMUTATED AND CONTINUOUS	GOOD	VERY GOOD	FAIR	9-12 DB

FIGURE 5-1 TELEMETRY SYSTEMS COMPARISON

BIBLIOGRAPHY

	TITLE	AUTHOR	PUBLISHER
1.	Aerospace Telemetry	Harry Stiltz	Prentice Hall
2.	Telemetry Systems Study	Ford Motor Company	U.S. Army Signal Research and Development Laboratories
3.	Proceedings from the National Telemetry Conferences	Years 1960, 1962 and 1964	
4.	Vendors Literature (Major Sources)	EMR Vector Parsons RCA Colvin Standard Control Fenwal Fairchild Electro Statham Bourns Budd Instrument Hidyne Bendix Pacific Honeywell Chrysler IDS Airpax	

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